

TOWARDS AN AUTONOMOUS WORLD:
Making Sense of the Potential Impacts of Autonomous Vehicles

by

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In Partial Fulfillment
of the Requirements for the Degree of
Masters of City and Regional Planning in the
School of City and Regional Planning

Georgia Institute of Technology
May 2014

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Planning as a profession covers many different facets even though the traditional role of a planner is thought of as dealing with land use and zoning. Taking this narrow view of planning misses many of the roles planners perform. One important role planners can have is that of an informer and consensus builder. By using the broad array of skills that planners have, a planner can help policymakers and the citizenry understand the impacts certain changes will have on the built environment and society. Further, planners can help develop a vision for embracing change while limiting the negative impacts of change.

This paper will seek to inform planners, policymakers, and the public about the potential benefits and impacts autonomous vehicles will have on the urban environment and society in the coming decades. This paper will lay a foundation for the issues planners and policymakers should begin to consider when deciding whether or not to embrace autonomous vehicles. Because this technology is moving along an exponential curve, if we do not begin to consider the effects it will have, then we may find ourselves unable to properly plan and prepare for this technology in the future.

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(1) Introduction

Planners have often dealt with technological innovation, however, one example of how well we dealt with that innovation can be seen in almost every metropolitan region. The suburbs, for the most part, are the result of transportation innovations that allowed people to “escape” the city. As a concept, the suburbs promised a venue for civic engagement and an escape from the ills of the city that had developed during the industrial revolution. Many believed that the city had become too crowded, too polluted, and too unhealthy. Technological innovation in transportation provided a mechanism for escaping the ills of the city and reclaiming our civic engagement. As transportation allowed people to move farther out, people began to trade-off housing costs for transportation costs. As transportation technologies progressed from streetcars/trolleys to automobiles, the distance to the suburbs was able to expand because cheaper land was accessible. Without natural boundaries or political boundaries to stop the growth, the mobility afforded by the automobile helped catalyze what we now know as sprawl.

Another catalysts for sprawl, some would argue, was the Supreme Court decision of *Village of Euclid v. Ambler Realty Co.*, 272 U.S. 365 (1926).¹ Those who argue that sprawl was catalyzed by this decision take the position that planners took the new found separation of uses ruling to the extreme. The separation of uses in conjunction with automobile mobility enhancements allowed by the Federal Highway Act provided the means for making the United States dependent on the automobile.² In a sense, we took the conceived beauty of the suburbs and disfigured it.

¹ Rodriguez, J. (2013). Special Section: Perspectives on Sprawl Development and Growth. *Leadership and Management in Engineering*, 13(3), 121-122.

² Putnam, R. D. (2000). *Bowling alone: The collapse and revival of American community*. Simon and Schuster.

Because we let the suburbs get away from us, the suburbs, and by extension the city, became car dependent environments. This car dependence helped turn downtowns and suburbs into large, fast moving roadways and large tracts of land dedicated to parking. Where cities and suburbs were once pedestrian focused,³ they became automobile focused.⁴ As this shift occurred, the automobile became a necessity.⁵ Some would argue that the suburbs – partially due to the car dependence of them – have largely been a failure, and that failure can, and should, partially rest on us as planners.

Today, planners and policymakers must ask themselves whether or not the United States can realistically move away from its automobile dependence. Because this author believes that the automobile will continue to be an integral part of our transportation system for the foreseeable future, this paper will seek to inform planners, citizens, and policymakers on how autonomous vehicles can potentially provide a solution to the issues currently associated with the automobile. Further, this author believes that, if planned for correctly, autonomous vehicles can potentially reshape our cities in a way that is less focused on the automobile. Thus, we can shift our built environment away from one that is automobile dependent back to one that considers the automobile as one of many factors.

Therefore, this paper will seek to answer whether autonomous vehicles provide a potentially better source of transportation than current transportation options such as the automobile. And, if so, what are some of the impacts, costs, and benefits autonomous vehicles will have on society and the built environment?

³ Some cities have a more pedestrian focused environment than others.

⁴ For an interesting perspective on this, read: Kunstler, J. H. (1994). *Geography Of Nowhere: The Rise And Decline of America's Man-Made Landscape*. Simon and Schuster.

⁵ As we moved further out, the automobile become are most reliable mode of transportation from a cost perspective.

(1.1) Methodology

To help planners, citizens, and policymakers understand the impacts, costs, and benefits of autonomous vehicles and whether this technology is better than current options, this paper will look at how autonomous vehicles will impact transportation economics, society, and the environment. After analyzing the potential impacts of autonomous vehicles, this paper will discuss some initial consideration for how planners and policymakers can address the impacts autonomous vehicles may have on the built environment.

In order to provide these analyses and recommendations, this paper will briefly introduce autonomous vehicles and then conduct an extensive literature review on autonomous vehicle projections and models and basic transportation concepts. Then, this paper will analyze data from the Texas A&M Urban Mobility Report, the Environmental Protection Agency (EPA), the National Highway Traffic Safety Administration (NHTSA), Zillow, the Department of Transportation (DOT), the Housing and Transportation (H&T) Affordability Index, the Brookings Institute, and the literature to create projections, analyze costs, and provide information on the impact of our current transportation culture and whether autonomous vehicles may change the economics, societal impacts, and environmental impacts of transportation system. Then, this paper will provide a table of the costs and benefits associated with transitioning to an autonomous vehicle world. Finally, this paper will conclude with thoughts and questions for planners and policymakers to consider.

(2) Overview of What this Paper means by Autonomous Vehicle

To help the reader understand what an autonomous vehicle is, this section will provide a brief overview of the vehicle and components. The NHTSA has provided the following definitions on autonomous vehicles (NHTSA 2013):

Level 0 (No Automation): The driver is in complete and sole control of the primary vehicle controls (brake, steering, throttle, and motive power) at all times, and is solely responsible for monitoring the roadway and for safe operation of all vehicle controls.

Level 1 (Function-Specific Automation): Automation at this level involves one or more specific control functions; if multiple functions are automated, they operate independently from each other. Further, the driver has overall control, and is solely responsible for safe operation, but can choose to cede limited authority over a primary control (e.g., adaptive cruise control), the vehicle can automatically assume limited authority over a primary control (e.g., electronic stability control), or the automated system can provide added control to aid the driver in certain normal driving or crash-imminent situations (e.g., dynamic brake support in emergencies).

Level 2 (Combined Function Automation):⁶ This level involves automation of at least two primary control functions designed to work in unison to relieve the driver of control of those functions.

Level 3 (Limited Self-Driving Automation):⁷ Vehicles at this level of automation allow the driver to cede full control of all safety-critical functions under certain traffic or environmental conditions. In these conditions, the driver relies heavily on the vehicle to monitor for changes and transition back to driver control if necessary. The driver is expected to be available for occasional control, but with sufficiently comfortable transition time.

Level 4 (Full Self-Driving Automation):⁸ The vehicle is designed to perform all safety-critical driving functions and monitor roadway conditions for an entire trip.

⁶ Level 1 and Level 2 are where most current vehicles stand in terms of automation.

⁷ Level 3 is the level of automation the Google Car currently has. This is also the level of automation most current legislation deals with. It is expected to be available commercially in the next few years.

⁸ This is the future of self-driving vehicles and will be where this report will spend most of its focus

Given the current advancement of autonomous vehicle technology along what appears to be an exponential curve, the question becomes: *what does this technology mean for vehicles and humans in the future?* The National Highway Traffic Safety Administration (NHTSA) notes that:

America is at a historic turning point for automotive travel. Motor vehicles and drivers' relationships with them are likely to change significantly in the next ten to twenty years, perhaps more than they have changed in the last one hundred years. Recent and continuing advances in automotive technology and current research on and testing of exciting vehicle innovations have created completely new possibilities for improving highway safety, increasing environmental benefits, expanding mobility, and creating new economic opportunities for jobs and investment. The United States is on the threshold of a period of dramatic change in the capabilities of, and expectations for, the vehicles we drive (NHTSA 2013).

Assuming the legal and policy issues surrounding autonomous vehicles are solved, understanding the impact of this change will be vital for planners and policymakers if they want to minimize any of the negative externalities that may come along with autonomous vehicles.

Having laid a foundation for what an autonomous vehicle is, the literature review will provide the framework for understanding the impact these vehicles will have.

(3) Literature Review

The academic literature on the potential impacts of autonomous vehicles is an evolving and growing area of study. Fagnant and Kockelman point out that there are still important research gaps include predicting how travel demand patterns will change, how intersections can best be managed, and how vehicle miles traveled (VMT) and vehicle emissions will change (Fagnant & Kockelman 2014). With this research, regional planners could incorporate many AV impacts in their travel demand models, traffic delay forecasts, air quality estimates, and related decision-making processes (Fagnant & Kockelman). For now, planners can still benefit from the

majority of the literature that tends to focus on the traffic safety and congestion benefits that may result from a shift to autonomous vehicles. Planners may also benefit from the smaller percentage of the literature that looks at the behavioral shifts and environmental impacts autonomous vehicles may have.

In order to best inform policymakers and to provide a full picture of the potential impacts of this technology, this literature review will be broken into two sections. The first section will focus on the literature relating to autonomous vehicles. The second section will focus on transportation literature that may help provide insight into travel behavior and mode choice. Together, these sections can help planners and policymakers generally understand the impact autonomous vehicles may have.

(3.1) Current Literature on Autonomous Vehicles

Level 3 autonomous vehicles are poised to be on our roads by the end of the decade. As of September 2013, Google had logged over 500,000 miles on public roadways using cars equipped with autonomous technology (Fisher 2013). Additionally, multiple manufactures such as Audi, BMW, GM, Ford, Mercedes-Benz, and Volvo have begun testing driverless systems, and many of these manufacturers intend to have commercially viable autonomous vehicles by 2020 (Eno 2013 & KPMG 2013). Further, as of March 2014, four states – Nevada, California, Florida, and Michigan – have passed legislation enabling autonomous vehicle testing on their roads,⁹ and another 18 states have proposed autonomous vehicle legislation.¹⁰ The fact that over 20 states have introduced over 40 pieces of legislation on autonomous vehicles – and that multiple manufacturers are looking to create a commercially viable vehicle in the next few years

⁹ Washington D.C. has also passed legislation.

¹⁰ See Appendix A for a Table of State Legislation

– indicates that there may a dramatic shift in personal transportation on the horizon. This shift will be even more dramatic as vehicles evolve from Level 3 to Level 4 in the next 20 to 30 years.¹¹ Because fleet turnover takes about 10 years, there will be a lag between when the technology is commercially available and when there is significant market penetration, but understanding the impacts are vital for planners and policymakers.

(a) *How do autonomous vehicles improve upon business-as-usual?*

Without autonomous vehicles, the Texas Transportation Institute’s 2011 Urban Mobility Report projects that by 2020, U.S. travelers will experience around 8.4 billion hours of delay while wasting 4.5 billion gallons of fuel, at an annual economic cost of \$199 billion (Schrank & Lomax 2011).¹² The KPMG 2012 and 2013 white papers on autonomous vehicles predict that autonomous vehicles will be able to reduce some of the negative externalities associated with driving (KPMG & CAR 2012 & KPMG 2013). While the reductions in these negative externalities will likely not be seen until after 2020, studies indicate that even small market penetration levels of seven to ten percent can cause noticeable reductions in externalities (Shladover et al. 2012).

For example, Shladover et. al. estimates that cooperative adaptive cruise control (CACC), a potential feature of autonomous vehicles, deployed at 10 percent, 50 percent, and 90 percent market-penetration levels will increase lanes’ effective capacities by around 1 percent, 21 percent and 80 percent, respectively (Shladover et al. 2012). Currently, vehicles moving at free-flow speeds on a freeway use only 11% of the length of the lane, while the remaining 89% of the

¹¹ The shift from Level 3 to Level 4 has the potential to impact the current understanding of ownership that we have today. A Level 4 vehicle would be capable of providing taxi-like services whereas a Level 3 vehicle would still need a driver in the front seat.

¹² This projection assumes \$17 per person-hour value of travel time, \$87 per truck-hour value of travel time, and statewide average gas prices from 2010

lane length represents the gaps that the drivers need to maintain behind other vehicles in order to feel safe and comfortable in their vehicle (Smith 2012). More precise throttling and braking could facilitate lower vehicle headways and even accommodate closely-spaced vehicle platoons, both of which could significantly increase lane capacity (Smith 2012).

If vehicles are equipped with just a few autonomous vehicle technologies such as CACC and traffic-flow-smoothing capabilities, at the 10 percent AV-market penetration level, freeway congestion delays for all vehicles are estimated to fall 15 percent, mostly due to smoothed flow and bottleneck reductions (Shladover et al. 2012). At the 50 percent market penetration level, a cloud-based system is assumed to be active, and further capacity enhancements of 20 percent may be realized (Shladover et al. 2012). Finally, at the 90 percent level, freeway congestion is assumed to fall by 60 percent, with the near doubling of roadway capacity and dramatic crash reductions (Shladover et al. 2012). The Eno report suggests that because capacity and delay are not linearly related, congestion abatement may be even greater than these predictions at the 90 percent market penetration level (Eno 2013).

In addition to congestion reduction, autonomous vehicles will also likely reduce the need for new infrastructure. KPMG estimates that platooning of vehicles could increase highway lane capacity by up to 500 percent (KPMG & CAR 2012). Autonomous transportation could also “bring the end to battles over the need for (and cost of) high-speed trains;” autonomous vehicles with the ability to platoon – perhaps in special express lanes – might provide a more flexible and less costly alternative (KPMG & CAR 2012). Parking, too, will be affected – vehicle sharing would keep vehicles in more constant use, serving more people and reducing demand for parking infrastructure (KPMG & CAR 2012). A 10 percent reduction in need for

infrastructure investment would result in savings of \$7.5 billion per year, or \$75 billion per decade compared to current infrastructure expenditures (KPMG & CAR 2012).

Finally, the literature suggests that autonomous vehicles could contribute to a significant redefinition of vehicle ownership and expand opportunities for vehicle sharing (KPMG & CAR 2012). “Even when vehicle usage is at its peak – near 5:00 p.m. in the U.S. – fewer than 12 percent of all personal vehicles are on the road, which means, of course, that 88 percent are not in use”(KPMG & CAR). If vehicles can drive themselves, they can be summoned when needed and returned to other duty when the trip is over (KPMG & CAR). Thus, travelers would no longer need to own their vehicles.

(b) *What is the impact of shifting to car-sharing and carpooling?*

Because the literature suggests that autonomous vehicles may change car ownership models, it is important to also understand the literature on car-sharing and carpooling, some of which overlaps with the autonomous vehicle literature.

A Lawrence Burns et al. study assessed the impact of carpooling and car-sharing on autonomous vehicles. This study used queuing and network modeling approaches to develop an analytical model to relate the area of the region, the mean trip length, the mean trip rate and how this varies throughout the day, mean vehicle speed, the average fixed time needed per trip, the fleet size, and vehicle cost parameters to shared, driverless vehicle fleet performance and cost (Burns et al. 2013). The analysis showed that autonomous vehicles could provide better mobility experiences at radically lower costs in a variety of land use settings (Burns et al. 2013). More specifically, the study found that shared, driverless vehicle fleets result in greater efficiencies, cost savings, consumer convenience, and sustainability benefits (Burns et al. 2013).

Even without autonomous vehicles, car-sharing provides a promising model for vehicle ownership. A 2009 study by Susan Shaheen et al. showed that one of car-sharing's most notable effects on transportation is reduced vehicle ownership. According to her study, car-sharing can potentially remove between 4.6 and 20 cars (per shared-use vehicle) from the transportation network (Shaheen et al. 2009). Further, a study by Jörg Firnkorn and Martin Müller found that free-floating car-sharing (a concept relatable to the capabilities of autonomous vehicles) could reduce car ownership as well (Firnkorn & Müller 2011). This study found that free-floating car-sharing could also reduce total emission over a 5 year period (Firnkorn & Müller 2011). However, a study by Spieser et al. noted that one of the weaknesses of car-sharing models is the lack of one-way rental options (Spieser et al. 2014). The Spieser et al. study noted that even when car-sharing offered a one-way rental, it often suffered from limited car availability (Spieser et al. 2014).

From an economic prospective, car-sharing may also be more favorable than major road construction. A 2000 study by Fellows and Pitfield used macroeconomic cost benefit analysis techniques to find the net present value of a car-sharing scheme. This analysis then related the net present value of the car-sharing model with that of major road schemes. The study found that even with relatively low car-sharing usage, the net present value of a car-share model compared favorably with two major road schemes prior to the subtraction of costs of construction, land take, disruption etc. for the road schemes (Fellow & Pitfield 2000). The importance of this model for planners is that car-sharing as a means for reducing congestion and reducing emissions can potentially be encouraged and incentivized at a fraction of the implementation cost of a major road scheme (Fellow & Pitfield 2000).

In addition to car-sharing, another applicable model for autonomous vehicles may be carpooling. A study conducted by Hai-Jun Huang et al. outlines three approaches to studying carpooling. The first approach involves estimating the ridesharing potential of an area by considering the process and conditions of formation of a group who will travel together in a common vehicle (Huang et al. 2000). The second approach of predicting ridesharing demand is based on utility maximization principle by viewing ridesharing as an individual or household travel decision (Huang et al. 2000). The third approach considers demand and supply effects to obtain equilibrium traffic flows, in which ridesharing plays a role of reducing traffic congestion through commuters' modal shift (Huang et al. 2000). By analyzing the model solutions, planners can obtain explanations for how carpooling may be affected by fuel cost, assembly cost, values of time, preferential or attitudinal factors, and traffic congestion (Huang et al. 2000).

(c) What do the autonomous vehicle models suggest?

Due to the potential reduction in the economics of driving and the shift autonomous vehicles may have on our traditional view of vehicle ownership, recent studies have started to analyze the economic, travel, and environmental impacts of a world with autonomous vehicles.

A 2013 study by Burns et al. looked at whether five emerging technology and business enablers could provide better mobility at a lower cost than what is present today (Burns et al. 2013). The study looked at three urban scenarios – Ann Arbor, Michigan; Manhattan, New York; and Babcock, Florida – and used analytical and simulation models to estimate the cost and performance of shared fleets of autonomous vehicles compared to the current cost and performance of non-autonomous vehicles (Burns et al. 2013). The study found that costs were significantly less in all three scenarios with autonomous vehicles (Burns et al. 2013). These results suggest that from an economic and performance standpoint, consumers would see cost

reductions and benefits from a fleet of shared autonomous vehicles over their traditional car ownership or other transportation uses.

Recognizing that fleets of autonomous vehicles can be cheaper than personal automobiles, a 2014 study by Spieser et al. evaluated the potential benefits of an autonomous vehicle fleet in Singapore (Spieser et al. 2014). This study examined replacing all modes of personal transport in Singapore with a fleet of shared autonomous vehicles (SAVs). Singapore provided the authors with a promising case study because of its high population density, its increasing traffic congestion, and its limited ability for roadway expansion (Spieser et al. 2014). The authors hypothesized that if shared cars were able to return to a parking or charging station, or drive to pick up the next customer by themselves, sharing would indeed provide a similar level of convenience as private cars, while providing the sustainability of public transport (Spieser et al. 2014). The model the authors used sought to quantify the user experience at different fleet sizes. The study found that with 300,000 SAVs, peak wait times were reduced to less than 15 minutes – an acceptable wait time (Spieser et al. 2014). At this level of service, 300,000 SAVs could replace the 779,890 personal vehicles operating in Singapore in 2011 (Spieser et al. 2014). Further, this level of service could be provided at 50 percent of total mobility costs (both the explicit and implicit costs of vehicle usage) compared to individually owning and operating a vehicle.

One final study found in the literature looked at the travel and environmental implications of small-scale SAVs. This 2014 study by Fagnant and Kockelman used agent-based modeling to determine the potential behavioral shifts and environmental impacts of SAVs (Fagnant & Kockelman 2014). The authors recognized, like the Spieser et al. study, that SAVs can help overcome the barriers faced by current car-sharing models by providing better access to vehicles,

shorter wait times, and little to no walking in order to access a vehicle (Fagnant & Kockelman 2014). Unlike the Spieser et al. study, Fagnant and Kockelman only sought to model the implications of a scenario with three and one-half percent SAVs. The model used suggested that even with this relatively small number of autonomous vehicles, each SAV could serve approximately 31-41 travelers per day, with an average wait time under 20 seconds (Fagnant & Kockelman 2014). The study also found that less than .5 percent of travelers waited more than 5 minutes for a SAV (Fagnant & Kockelman 2014). Due to the level of service obtainable in the model, the authors noted that on average, each SAV has the ability to replace nearly 12 privately owned vehicles (Fagnant and Kockelman 2014).

(d) What are some of the potential negative consequences of autonomous vehicles?

Despite the benefits of autonomous vehicles highlighted in the literature, the literature also suggests that a world with autonomous vehicles could have some negative impacts as well. Both The Eno Center for Transportation and Bryant Walker Smith predict that a shift to autonomous cars could ultimately lead to more VMT, more sprawl, and more emissions (Eno 2013 & Smith 2012). Smith, taking an induced demand approach, suggests that the added capacity resulting from greater efficiency could lower the internal price of a motor vehicle trip, which in turn could increase both near- and long-term demand (Smith 2012). Further, despite the increased highway carrying capacity of a world with autonomous vehicles, average delays during peak periods may stay roughly the same (Smith 2012). Similarly, while traditional car-sharing studies estimate that North American car-sharing members reduce their driving distances by 27% (Shaheen et al. 2013), Fagnant and Kockelman's model showed that with SAVs, vehicle miles traveled actually increased (likely due to the decreased cost of vehicle travel). This

suggests that even though emissions per vehicle mile traveled may decrease, total emissions may actually increase due to increased VMT (Smith 2012).

Given that there are negative externalities associated with autonomous vehicles, it is important for decision makers to understand these so that they can plan for these externalities in a way that helps reduce their impact. One way for planners and decision makers to limit these impacts is to have a basic understanding of some of the fundamentals of transportation literature. The proceeding section will provide a basic review of this.

(3.2) Basic Transportation Literature – Drivers of Mode Choice

A world where autonomous vehicles replace traditional motor vehicles is fast approaching. While the literature on autonomous vehicles discussed previously focused on the impacts of the technology, understanding what makes people travel by what mode is also important for planners to understand. For the purposes of this paper, this section of the literature will look at the influence of urban form and self-selection on transportation, and the influence of accessibility, mobility, and induced demand on travel decisions. A basic understanding of these concepts in conjunction with an understanding of autonomous vehicles can help planners and policymakers make informed decisions about autonomous vehicles.

(a) What is the impact of the built environment on transportation?

The influence of urban form on travel is the subject of much debate, but there are important points that can be drawn from the literature. The first point that can be drawn is that the built environment has a distinct influence on travel behavior even after controlling for self-selection (Mokhtarian & Cao 2008). After reviewing nine approaches used to address the issue of residential self-selection, Mokhtarian and Cao noted that not only did walking-oriented people

moving to walking-oriented environments walk more, but auto-oriented people moving to walking-oriented environments were expected to walk somewhat more as well (Mokhtarian & Cao 2008).

A second point that can be drawn from the literature is that the interaction between land use policies and modal choice is complicated. A survey of the transportation/land-use literature by Badoe and Miller found that the results of land use policies on modal choice is mixed (Badoe & Miller 2000). Badoe and Miller found that some of the literature suggests that land-use policies emphasizing higher urban densities, traditional neighborhood design, and land-use mix do result in declines to auto ownership and use, while enhancing patronage of the more environmentally friendly modes of transit and walk (Badoe & Miller 2000). Other studies, however, find this impact to be at best very weak (Badoe & Miller 2000). Ming Zhang's report highlights the fact that the relationship between land use and travel behavior is complex and multidimensional, because there are multiple attributes of land use intertwining with various aspects of travel behavior (Zhang 2004).

One of the causes of the mixed results may be a factor of the scale being used in the study and the difficulty in identifying the correct variables to measure. For example, a Reid Ewing et al. study measured sprawl in multiple dimensions at the regional level and investigated its impact on an array of transportation-related outcomes. For most outcomes, sprawling regions performed less well than compact ones (Ewing et al. 2003). Two other studies have also found sprawl to perform less well than compact regions (Shammin et al. 2010 & Zolnik 2012). A Shammin et al. study found that sprawl was 17-19% more energy intensive than compact living (Shammin et al. 2010). Further, in 2012, Edmund Zolink noted that previous literature on regional scale interactions suggest that household expenditures on transportation are \$1300 higher in more-

sprawling MSA than in less-sprawling MSAs (Zolink 2012). The Ewing study also found that a 25-unit per square mile increase in density was associated with a 2.95 percentage rise in public transportation mode share on the journey to work (Ewing et al. 2003). However, the Ewing study found that certain variables like average commute time and annual traffic delay per capita, did not clearly favor compactness over sprawl (Ewing et al. 2003).

At a neighborhood level, Robert Cervero and Roger Gorham found that there is an influence on commuting behavior between traditional neighborhoods laid out originally around transit stations and more recent, automobile-centric neighborhood patterns (Cervero & Gorham 1995). The study found that neighborhood design seems to affect the degree to which people drive alone to work, and the degree to which they walk or bicycle (Cervero & Gorham 1995). Transit neighborhoods tended to show lower drive-alone modal shares and trip generation rates than did their automobile neighborhood counterparts (Cervero & Gorham 1995). But, the study also found that people wanting to leave a traditional neighborhood are just as likely to drive their car as are people leaving from a more auto-oriented neighborhood (Cervero & Gorham 1995).

Finally, an analysis by Reid Ewing and Robert Cervero of the compiled literature on transportation and the built environment found that modes other than auto are more likely to be used for non-work trips in a traditional neighborhood (older, mixed use, grid) (Ewing & Cervero 2001). They also found that VMT is lower where household densities are higher or more employment is accessible by either mode, vehicle trips are more frequent where more employment is accessible by auto and less frequent where more employment is accessible by transit, parking supplies discourage transit commuting and walk/bike access modes to rail stations, and transit share or work trips is lower in downtowns with more parking spaces per employee (Ewing and Cervero 2001).

Despite the mixed literature on the impact of the built environment, Randall Crane notes that the built environment affects how often and how far people drive or walk or when they will take the bus or train (Crane 2000). Crane's report notes that the difficult task is measuring how changes in urban form affect travel behavior (Crane 2000). This, Crane notes, will continue to be, and should be, a focus of research.

(b) *What are the roles of accessibility, mobility, and induced demand?*

Outside of the role the built environment plays in determining modal choice, a few other determining factors are accessibility, mobility, and induced demand. The influences these factors tend to have on modal decisions are via the economics of travel decisions.

Accessibility can often be thought of as the potential for interaction (Handy 2002 & Hansen 1959). More choices in both destinations and modes of travel mean greater accessibility (Handy 2002). However, much of the policy and built environment in the United States is focused on mobility (Levine et al. 2012). This focus on mobility can be seen in the metrics used to evaluate performance of the transportation system (Levine et al. 2012). Under these mobility-based metrics, planners, engineers, and the general public deem rapid movement as a definitive success (Levine et al. 2012). Yet, a building block of modern transportation planning is the notion that "the demand for transportation is derived; that is, people rarely consume transportation for the pleasure of movement per se, but rather travel in order to reach opportunities available at destinations" (Levine et al. 2012 & Meyer & Miller 2001).

If we are using mobility based metrics, but transportation is derived, then we are focusing too much on the means rather than the ends. Further, if the desired end is access at the end, then increased mobility should only be desired to the extent that it also increases accessibility (Levine

et al. 2012). Too much focus on mobility has the potential to allow travel to more remote locations at higher speeds, but the distance between these destinations can demand more travel compared to more compact and clustered urban arrangements where travel is slower (Levine et al. 2012). A continuation of congestion relief through added capacity can in turn induce destinations to move farther apart; thus, increased mobility “can be associated, over the long run, with more time and money spent in travel, rather than less” (Levine et al. 2012). Because our time is limited, too much focus on mobility may be inefficient in the long-run.

Consequently, the Levine et al. study found that “decreasing mobility – in terms of speed-reduction – may not always be a bad thing” (Levine et al. 2012). At times, increasing density at the expense of increased mobility may be accessibility enhancing when the effect on accessibility outweighs the speed-reduction effect (Levine et al. 2012). But, one important point to remember is that the demand for driving appears to be relatively inelastic (Handy 2002). Research has shown that steady growth in vehicle travel has slowed but not stopped even as congestion levels have dramatically increased (Handy 2002). Thus, increased accessibility may not change modal choice even if the economics suggest that it should because “most Americans on at least some occasions actually enjoy driving” (Handy 2002). But, increased choice in travel to a destination and in what is available at the destination may induce some to shift travel modes.

The focus on increased mobility has led many to look at the impact this has on demand for travel. The economic theory of supply and demand provides an explanation of the induced travel effect. New capacity reduces the price of travel by reducing travel times and, in economic terms, shifts the supply curve (Handy 2002). “As the price of travel goes down, the consumption of travel goes up; the supply curve intersects a new point on the demand curve” (Handy 2002). But, the induced demand is hard to document. A Noland and Lem review found that there was a

link between increased lane mile and decreased travel time with increased VMT (Noland & Lem 2002). However, a Mokhtarian et al. study refuted the findings found in some of these studies (Mokhtarian et al. 2002). Another form of induced demand posited by Qing Su's suggests that oil efficiency improvements may lead people to drive more and consume more fuel than they would if their vehicle miles traveled (VMT) remains unchanged (Su 2011). Even if the effect of induced demand is hard to document, the economic theory behind it suggests that it should be an important consideration for planners. The assumption should be that people are rational actors.

(c) What do the models suggest about mode choice?

The literature on transportation models suggests that there are various impacts on mode choice for different trips (Boarnet & Crane 2001; Chatman 2008; Salon 2009; Snellen & Timmermans 2002; & Zhang 2004).

A study by Marlon Boarnet and Randall Crane used microeconomic theory of travel to determine land use/transportation interaction. The study found that the empirical measurement of land use/transportation linkages appears quite sensitive to alternative behavioral and statistical assumptions, and the type and geography of the data (Boarnet & Crane 2001). Further, a study by Daniel Chatman suggests that when people engage in activities outside the home and workplace, they face time and money constraints that affect how frequently and for how much time they engage in those activities, and they experience travel itself as both an activity and as an integral part of that decision making process (Chatman 2008). Chatman's study found that a new transit-oriented development could make jobs or non-work activities accessible via rail or bus to more residences without increasing the time price of auto use (Chatman 2008). But, "if road design standards are relaxed, if network load density also increase, and in turn road speeds

decrease, auto mileage may decline, particularly if transit and walking options are available” (Chatman 2008).

A Snellen et al. study used a multilevel model and quasi-experimental design to find that urban form and network type have only a modest, yet present, effect on mode-choice decisions for frequently conducted activities (Snellen & Timmermans 2002). Further, Deborah Salon used discrete choice econometrics to model the joint choice of residential location, car ownership, and commute mode in New York City. This study found that New Yorkers are more sensitive to changes in travel time than they are to changes in travel cost (Salon 2009). The model predicts that the most effective ways to reduce both auto ownership and car commuting involve changing the relative travel times for cars and transit, making transit trips faster by increasing both the frequency and the speed of service and making auto trips slower (Salon 2009).

Finally, Ming Zhang used Consumer Choice Theory to suggest that any factors that change the relative attractiveness of travel modes will affect the traveler’s mode choices (Zhang 2004). His study found that decreased network connectivity at trip destinations resulted in a greater likelihood of driving alone (Zhang 2004).

Having laid the foundation for autonomous vehicles and basic transportation concepts, the next section of this paper will focus on an analysis of the current costs associated with our driving culture and the ways that autonomous vehicles may change these costs. This analysis will help planners and policymakers begin to determine the effect that this technology may have on transportation going forward.

(4) Analysis of Autonomous Vehicles

As the literature suggests, autonomous vehicles represent a potential shift in our current transportation system. Further, taking what we know from the literature about current drivers of transportation decisions, one can start to develop strategies and considerations for how to integrate autonomous vehicles in a beneficial manner. The first step in planning for autonomous vehicles is to analyze the current conditions. The next step is to determine what the future might be like with autonomous vehicles. Then, planners and policymakers can analyze the potential impacts of autonomous vehicles and begin to formulate strategies for integrating this technology into society and our urban environment.

The analyses in the following section will mainly use data for the United States, but it will also use data for Atlanta, Georgia and New York, New York to present specific examples for how autonomous vehicles may impact two very different cities.

(4.1) Cost of Vehicle Ownership - Household Costs

Research has shown that even when automobile usage is at its peak in the United States (around 5:00 p.m.) fewer than 12 percent of all personal automobiles are on the road (KPMG & CAR 2012). This means that even at peak automobile usage hours, 88 percent of automobiles are not in use (KPMG & CAR 2012). This indicates that there are likely more automobiles in the United States than are needed. Further, the typical automobile is parked for about 95 percent of its lifetime (Shoup 2005). Yet, Americans continue to pay for the high cost of automobile ownership.

(a) *Current data on the vehicle ownership costs*

According to recent data, the average cost of driving an automobile is \$10,374 per year (AAA 2013).¹³ About 65 percent of the cost of an automobile is attributable to ownership costs (tax, tag, insurance, etc.); only 35 percent of the cost is attributable to operating the automobile (AAA 2013).¹⁴ Further, recent data indicates that the average family has 1.95 automobiles per household (Sivak 2013a). So, taking the average cost of driving an automobile and combining it with the average number of automobiles per household allows an estimate of household expenditures on personal automobiles to be calculated. If a household has 1.95 automobiles, and drives each automobile 15,000 miles per year, that household will spend around \$20,000 per year on motor vehicle transportation.¹⁵ Even if a family only drives one automobile 15,000 miles per year, just by having the other .95 of an automobile means that they will still spend about \$16,000 per year on their motor vehicles.

While the amount of money spent on motor vehicle transportation calculated above may seem high, data from the Housing and Transportation (H&T) Affordability Index indicates that the calculations above are close to the transportation expenditures for a household in Atlanta, Georgia.¹⁶ Data from the H&T Affordability Index shows that the average household's transportation expenditures in Atlanta can range from 25.97 percent of their household income to 15.82 percent of their household income depending on whether they live inside or outside the city (See Figure 1).¹⁷

¹³ This average is for cars not SUVs or trucks. It also is for a person driving 15,000 miles per year.

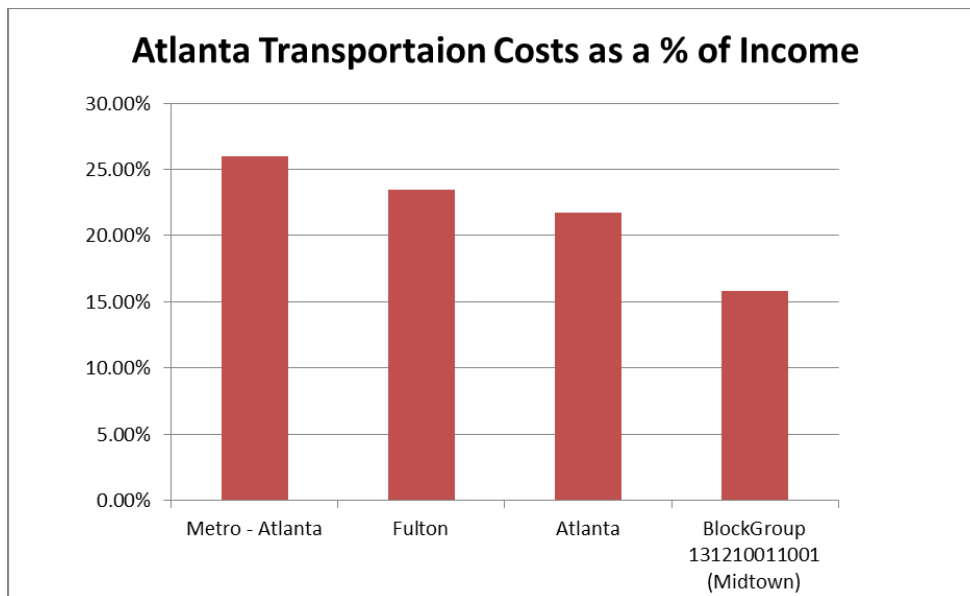
¹⁴ Because ownership costs are fixed, the operation cost per mile of a personal vehicle decreases as miles traveled increases. Thus, the costs associated with a vehicle become less the more one drives.

¹⁵ These numbers should decrease slightly over time as the AAA factors in financing charges in the ownership costs

¹⁶ <http://htaindex.cnt.org/map/>.

¹⁷ H&T Affordability Index uses an assumption of 2.79 people per household and 1.26 commuters per household.

Figure 1

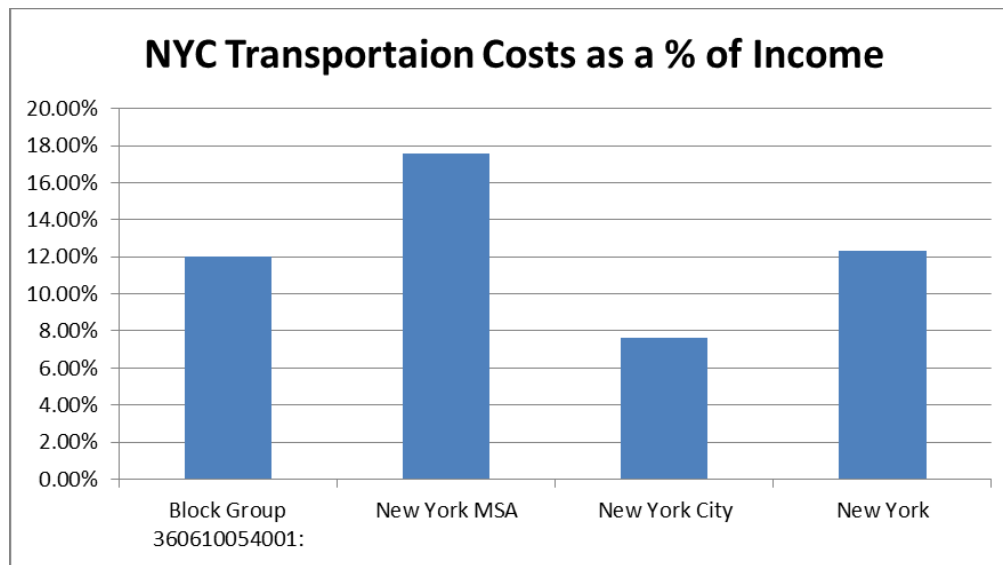


This means that an average household in Atlanta making \$58,390 will spend between \$15,163.88 and \$9,237.30 of their income on transportation.¹⁸ In New York City, however, a household will only spend between \$11,159.11 and \$7,613.65 of their household income on transportation (roughly 24 to 32 percent less than a household in Atlanta) (See Figure 2).¹⁹

¹⁸ \$58,390 is the income level used by the H&T Affordability Index. The 15.82% of household income spent on transportation is for a household in Block Group 131210011001.

¹⁹ The New York City data assumes 2.74 persons per household, 1.22 commuters, and an income of \$63,553. The \$7,613.65 spent on transportation is for households in Block Group 360610054001.

Figure 2



The difference in transportation expenditures between these two cities can likely be attributed to a couple of different factors: vehicle ownership, access to alternative transportation and, and access to jobs from transportation alternatives. As discussed above, automobile ownership can account for a significant portion of a household's expenditures. Further, in an area like New York City, the cost of owning an automobile tends to be higher than in an area like Atlanta because the use of an automobile is less subsidized (i.e. cost of tolls, parking, etc.) (See Table 1).

Table 1

Cost of Driving in NY vs. Atlanta		
	NYC	Atlanta
Yearly Amount spent on Tolls	\$1,430.00	\$0
Yearly Parking Expenses	\$5,172	\$1,200
Average VMT	26.84	32
Assumed Fuel Economy	20.374	20.374
\$/gal of Fuel	\$3.50	\$3.15
Average Fuel Spending	\$1,682.93	\$3,273.07
Total Costs	\$8,284.93	\$4,473.07
Total Costs + Ownership Costs	\$13,808.22	\$7,455.11

Taking into account only tolls, parking, and gas, a New Yorker will spend almost twice as much to drive 9800 miles per year as someone in Atlanta will spend to drive 21,300 miles per year.²⁰ This high cost of automobile ownership may help explain why only 43.5 percent of New York City households own an automobile while roughly 94 percent of households in Atlanta own a car (Sivak 2014 & Tomer 2011).

Another explanation for the difference in automobile ownership and transportation expenditures may be the low cost of alternative transportation coupled with access to alternative transportation and access to jobs from alternative transportation. In Atlanta, it would only cost an individual about \$1,140 a year to ride public transit.²¹ In New York City, this cost would only be \$1,345.²² Both of these cities offer public transit at costs significantly lower than those associated with automobiles, but a study for Brookings Institute notes that public transit is not always a viable option. For example, in Atlanta only 38 percent of working-age residents are near a transit stop (Tomer et al. 2011). Further, only 22 percent of jobs can be reached via fixed-route transit in 90 minutes (Tomer et al. 2011).²³ When looked at for zero-vehicle households, coverage increases to 68.5 percent and jobs access increases to 27.7 percent (Tomer 2011). In New York, on the other hand, 90 percent of working-age residents are near transit stops and 37 percent of jobs can be reached via fixed-route transit in 90 minutes (Tomer 2011). For households without vehicles in New York, 98.7 percent are near transit and 48.8 percent of jobs can be reached via fixed-route transit (only 49.6 percent of these zero-vehicle households are

²⁰ 9800 and 21,300 miles per year are the average yearly miles driven in New York City and Atlanta based off a report from Forbes Magazine. Available at:

<http://www.forbes.com/sites/christopherhelman/2011/05/10/americas-biggest-and-least-gas-guzzling-cities/>.

Toll and parking data were found using the internet.

²¹ Data from MARTA

²² Data from MTA

²³ According to the author, Fixed-route transit was used because service times could be measured. Alternative transit may in fact provide better jobs access.

considered low-income which may highlight the issue of self-selection discussed in the literature review).

For a visual of the difference in access, the rail transit maps for New York City and Atlanta are provided in Appendix B. As indicated in the data and shown on the rail transit maps, access to transit is much higher in New York City than in Atlanta. When coupled with the lower cost of alternative transit in New York City, it may help explain why a household in New York City spends less on transit than a household in Atlanta.

What this data shows is that there is room for improvement in both New York City and Atlanta. Even in a city like New York, autonomous vehicles may be able to provide better access and mobility than the current public transit system. This is probably even truer in an area like Atlanta that suffers from the negative impacts of sprawl (see e.g. Ewing & Hamidi 2014).

(b) Ownership costs with autonomous vehicles

Even though driving a vehicle may seem relatively inexpensive when all costs are not factored into the equation (i.e., maintenance, time, and fixed costs), the data above indicates that automobiles can account for a more significant amount of a household's expenses than one may realize. Further, if the full cost of using an automobile is not passed on to the consumer and households or individuals do not have easy access to public transportation and the capability of getting to where they want to go in a timely manner, households will likely continue to use their personal automobile even if public transportation is a cheaper alternative. Autonomous vehicles, on the other hand, can be cheaper than personal automobiles and provide better access than public transportation systems.

One of the main reasons autonomous vehicles are cheaper than personal automobiles, and in some instances public transportation, is the change in an individual's value of time associated with using an autonomous vehicle. As discussed in the literature review, studies on consumer cost savings from using autonomous vehicles is just beginning. However, these studies suggest that autonomous vehicles will be more cost effective than traditional vehicles (Spieser et al. 2014). The Spieser et al. study found that the cost of travel is about 31 percent less with shared autonomous vehicles than with human driven vehicles. Further, when the value of time is factored in, the total monetary cost associated with using a shared autonomous vehicle is 46.5 percent less than when using a human driven vehicle. Even a single occupant autonomous vehicle is 23.8 percent less costly than a human driven vehicle when the value of time is factored in. However, a single occupant autonomous vehicle is 13.5 percent more expensive than a human driven vehicle when only considering cost of travel (this increase is due to the assumption that individuals will drive more when their value of time associated with travel is less). So, if a household spent \$15,000 per year on vehicle travel, it would spend \$10,312 per year on vehicle travel in a shared autonomous vehicle world and \$8,023 when factoring in value of time savings. In an individual owner autonomous vehicle world, a household would spend \$17,031 on travel but only \$11,424 when value of time is factored in.

In some instances the savings and travel benefits of autonomous vehicles may outweigh those of alternative transportation options (Burns et al. 2013). Further, for areas with limited transportation access, or for areas with limited jobs access via transportation, autonomous vehicles may provide access to those who cannot afford a personal vehicle. The Burns et al. study found that "a shared, driverless vehicle fleet could compete strongly with the mobility services provided by yellow taxicabs and, to varying degrees, by buses, the subway, other for-

hire car services, hourly rental cars and personally owned cars” in an area like Manhattan (Burns et al. 2013). The Burns study also found that the cost of providing the yellow taxicab service is approximately \$4 per trip-mile compared with \$0.50 per mile for a shared, driverless vehicle (Burns et al. 2013).²⁴ Running the analytical model outlined in the Burns study shows that a fleet of 5,250 shared autonomous vehicles in a 100 square mile can provide service of 10,000 trips per hour at \$0.30 per trip mile with an average wait time of just .90 minutes.

(c) What does this mean to planners and policymakers?

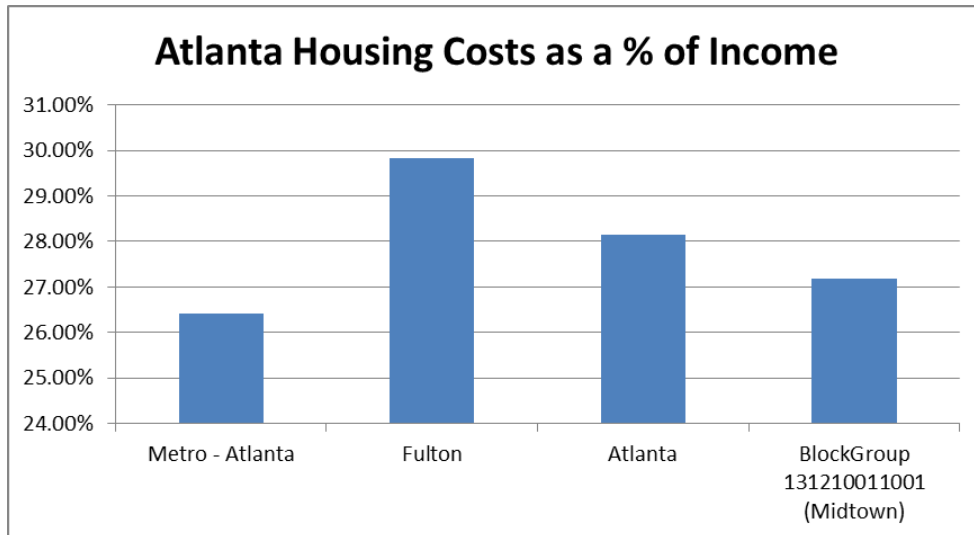
Autonomous vehicle can potentially provide automobile service at reduced costs compared to current automobile travel. As discussed in the literature review, travel and mode choice are a product of economics. Because autonomous vehicles can provide similar levels of service to personal vehicles at lower prices and potentially greater accessibility to those in need at similar prices as alternative modes of transportation, households may be more compelled to use them over other forms of transportation. Because transportation can be provided more cheaply, households may spend less income on transportation in a future with autonomous vehicles. Finally, individuals may have greater productivity during travel than they currently have in the human driven vehicle world. This increased productivity may further increase the savings associated with autonomous vehicles

A beneficial impact of reduced transportation costs is that if a household can spend less on transportation, they potentially have more money to spend on housing and other goods.

²⁴ These cost savings are the result of fewer taxis, less empty miles, and reduced labor costs of the driver.

Currently, a household in the metro Atlanta region tends to spend less on housing than a household living in the City of Atlanta (See Figure 3).²⁵

Figure 3

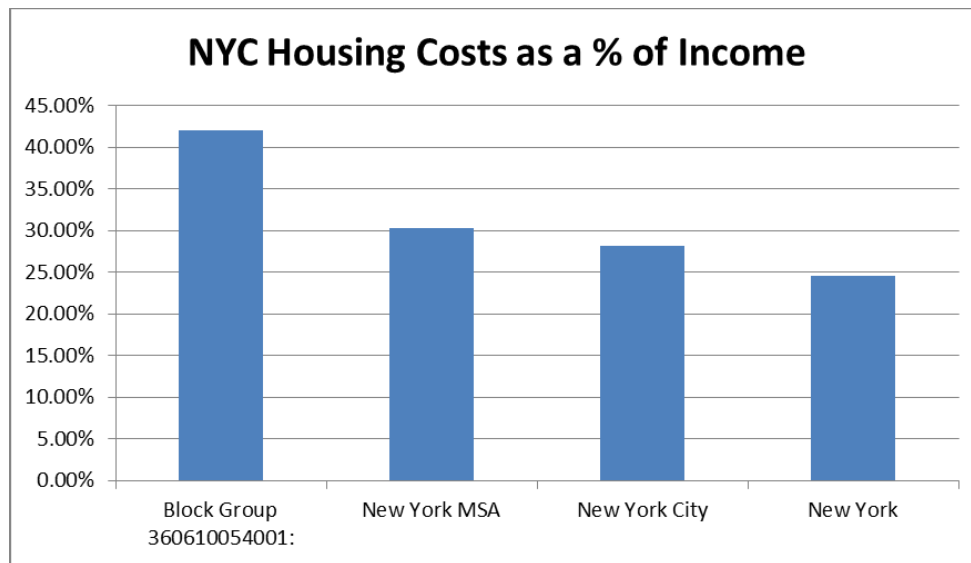


This is similar to the pattern seen in New York City. In the New York City metropolitan statistical area (MSA), the percentage of income spent on housing ranges between 30 percent and 42 percent (See Figure 4).²⁶

²⁵ Once again, this assumes a household income of \$58,390; The Bid Rent Map for Atlanta in Appendix C may help explain why the Fulton county % is so high

²⁶ This assumes a household income of \$63,553

Figure 4



This equates to a roughly 15 to 55 percent increase over housing expenditures in Atlanta. Of note here is that the percentage of income spent on housing tends to increase as transportation expenses decrease. This indicates that there is an economic bid rent curve happening in these areas. Because we know cities are typically not perfectly mono-centric and rents never become zero, we know that there is not a perfectly linear bid rent curve (Heilbrun and McGuire 1987); but, if you look at the maps in Appendix C using Zillow housing price per square foot data at the zip code level, you can see a rough decrease in price per square foot of housing as you move away from the major commercial districts. This corresponds with the increased transportation expenditures and indicates that people may be trading off housing and transportation as suggested in an economic bid rent curve.

In a world with autonomous cars, households following an economic bid rent curve may choose to use the savings from autonomous vehicle transportation to move closer to the city, or they may choose to allocate the same percentage of income to housing and transportation and

move farther away from the city center. Thus, it is important for planners to consider the possibility of both a denser city and a more sprawling metropolitan region.

To prepare for the possibilities listed above, planners and policymakers may want to provide incentives for infill development, establish a growth boundary past which the municipality will not provide certain infrastructure, and/or look into transferable development rights. Because Level 4 autonomous vehicles are still 20-30 years away, planners and policymakers should have some time to study and implement a regime that will best fit a city's needs and political capabilities.

(4.2) Cost of Vehicle Ownership – Congestion

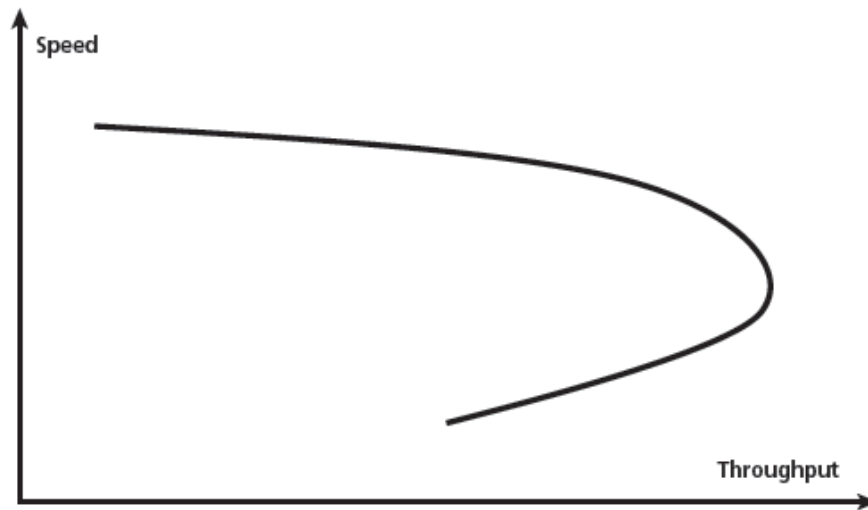
In addition to the personal costs associated with owning an automobile, there are also costs associated with congestion such as societal costs and government expenditures. Congestion is the result of recurrent and non-recurrent delays (Anderson et al. 2014). Recurrent delays occur in the same time and location on a daily basis and are the result of a market failure. Non-recurrent delays are typically the result of isolated incidents such as construction or traffic accidents. These congestion delays result in wasted time, excess fuel consumption, increased emissions, and economic waste. Often, a solution for the results of congestion is adding capacity via additional lanes to the road system (Fields et al. 2009). Autonomous vehicles offer a solution to the negative impacts of congestion and to the expense of adding lanes.

(a) Current data on congestion

In theory, a freeway operating under optimal conditions can serve a maximum of 2400 vehicles per hour per lane (Smith 2012). However, when plotted over time, observations of highway travel speed and traffic volumes form a backward-bending curve (see Figure 5).

Figure 5²⁷

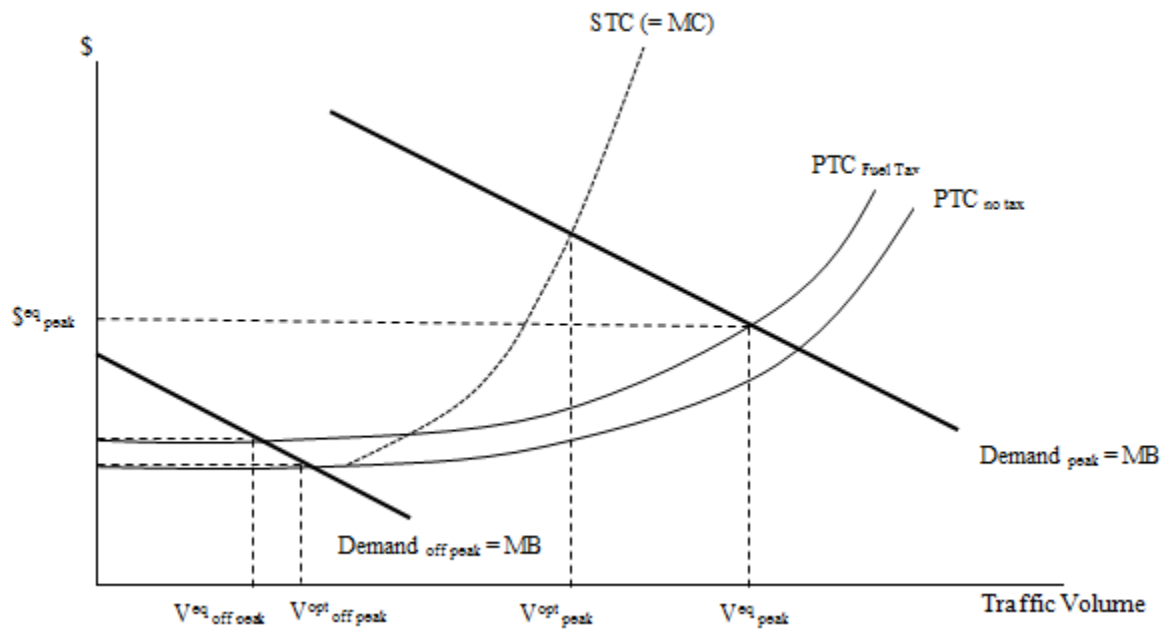
Relationship Between Roadway Speed and Roadway Throughput



This backward-bending curve is recognition of the fact that once optimum conditions are exceeded, additional vehicles trigger conditions that reduce throughput and speed. The result is congestion (Anderson et al. 2014 & Sorenson et al. 2008). Assuming a commuter has perfect information, the driver of the vehicle 2401 seeking to enter a one lane freeway would not enter the freeway because the cost of entering the roadway would exceed the marginal benefit of driving on the roadway. Instead, a rational commuter would find an alternative route or take a different mode when the roadway is at capacity. However, roadways often exceed capacity because commuters typically lack perfect information and because they value their private travel costs (PTC) below the true cost of driving (STC) (See Figure 6). This causes the peak traffic volume to exceed the optimal peak traffic volume. Thus, this results in a market failure (Moore & Thorsnes 1994).

²⁷ Source: Anderson, J. M., Kalra, N., & Stanley, K. D. (2014). *Autonomous Vehicle Technology: A Guide for Policymakers*. Rand Corporation.

Figure 6²⁸



Further, the market failure caused by marginal costs (MC) exceeding marginal benefit (MB) is congestion. This congestion results in many negative societal impacts such as wasted time, economic waste for commuters, and excess fuel consumption. Using data from the Texas A&M Urban Mobility report, we can project these impacts out to 2030 for Atlanta and for the 101 area average (See Figures 7-12).

²⁸ Source: Moore, T., & Thorsnes, P. (1994). *The transportation/land use connection* (No. PAS 448/449).

Figure 7

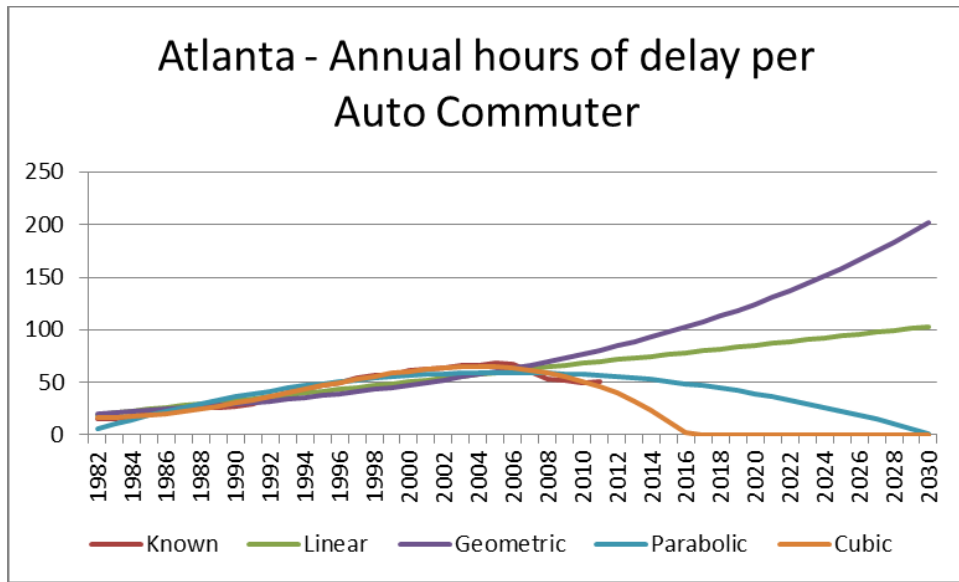


Figure 8

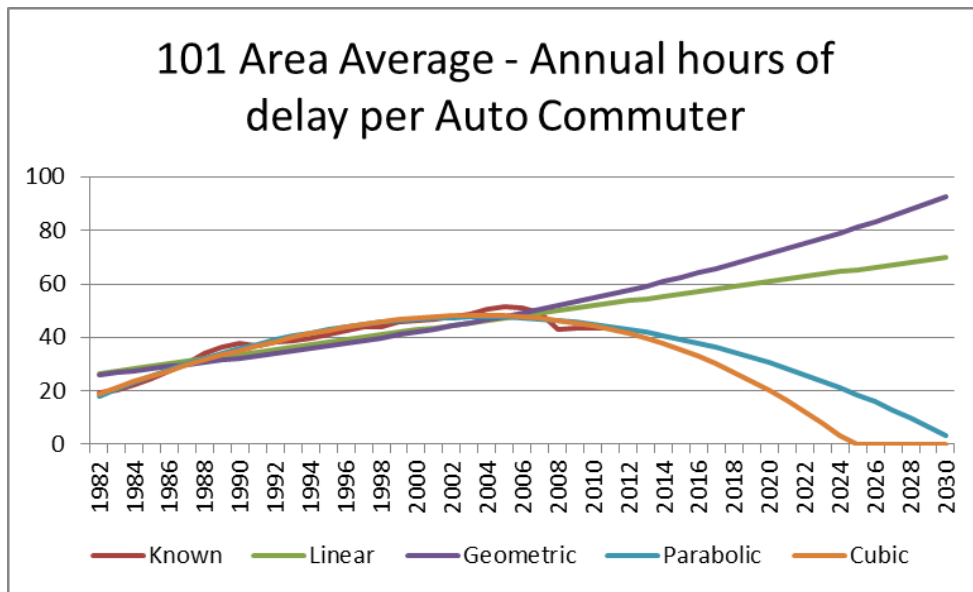


Figure 9

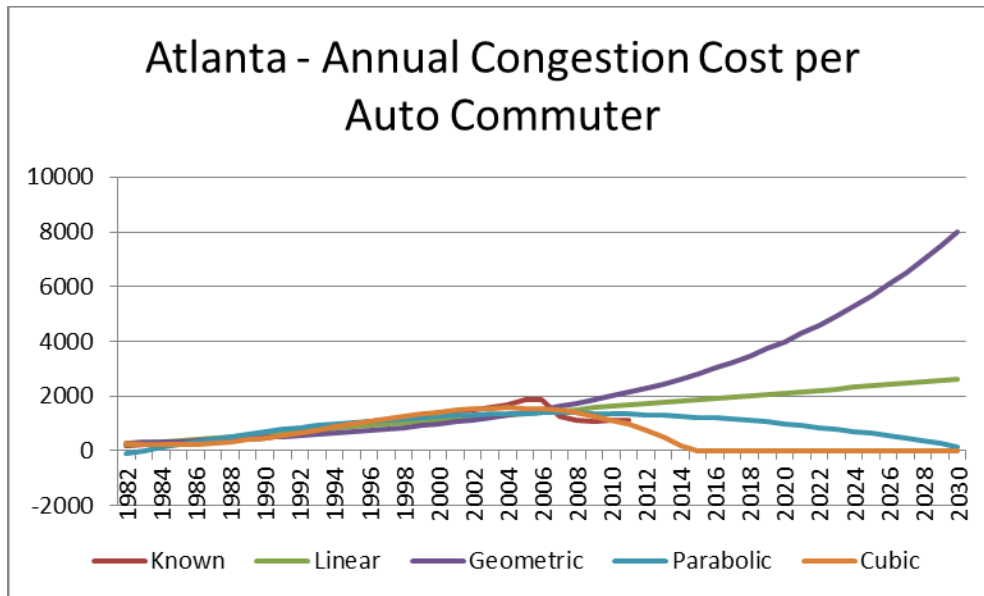


Figure 10

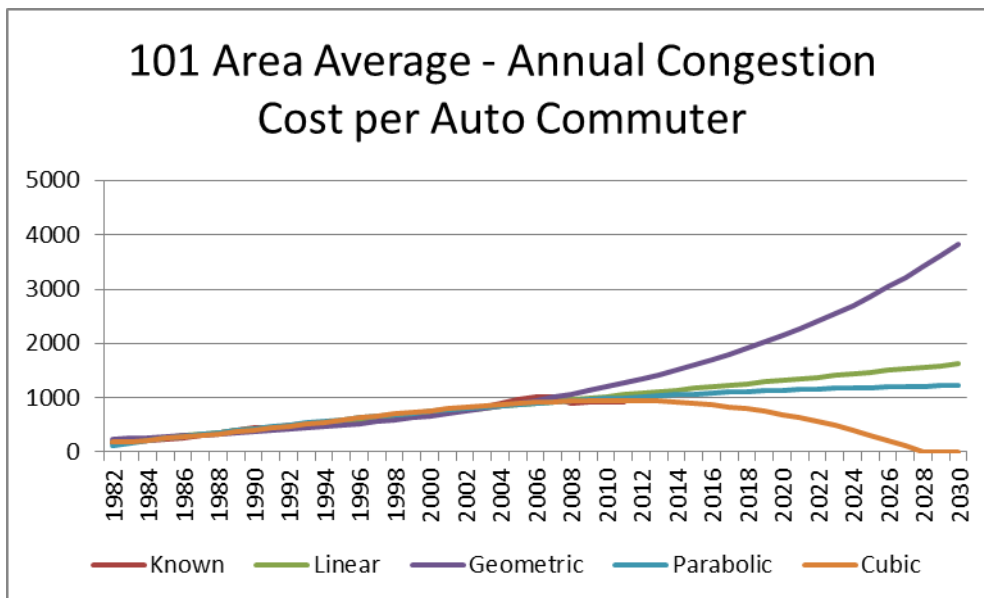


Figure 11

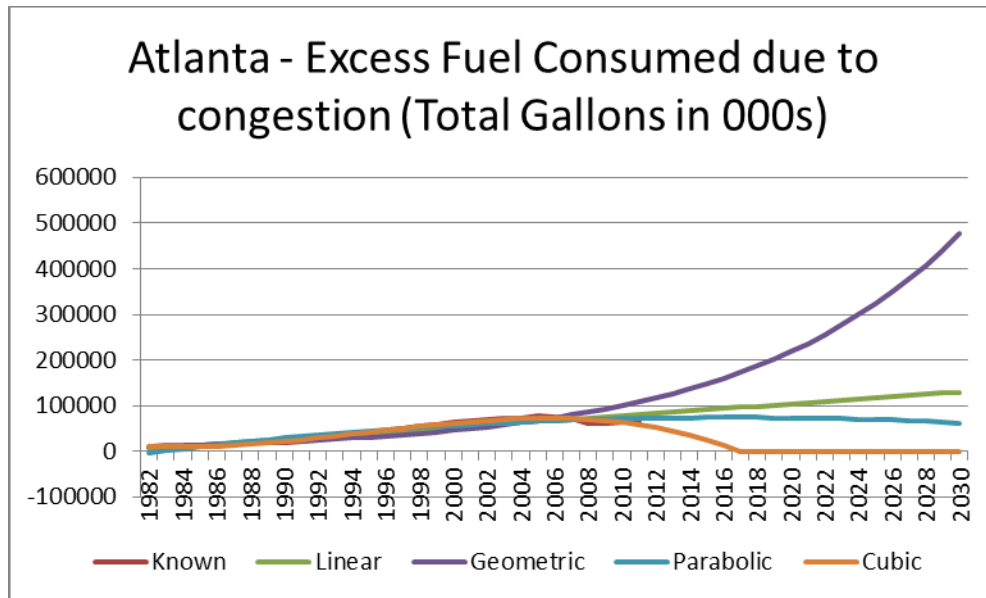
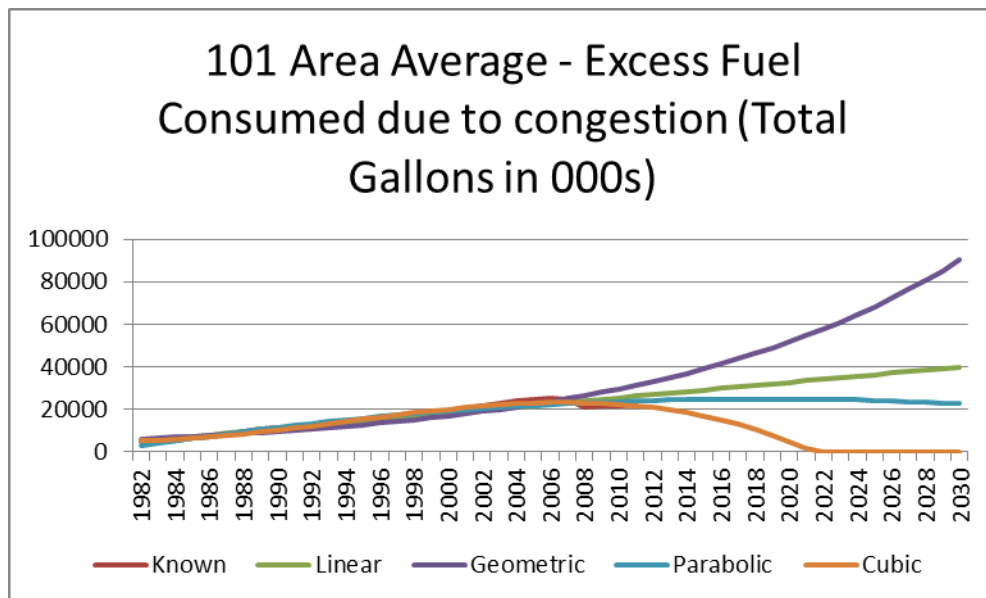


Figure 12



For the most part, these negative externalities of congestion will continue to get worse in the future if nothing is done to correct them. Often, the solution for these issues is building extra capacity. However, given population projections and projections on increased freeway miles and percent congested system, we can see that building extra capacity is not the sole fix for

congestion and the congestion impacts listed above (See Figures 13-18). Congestion and congestion impacts are projected to increase even as freeway miles increase; part of the reason for this may be the issue of induced demand (adding capacity can change the economics of driving a personal vehicle).²⁹

Figure 13

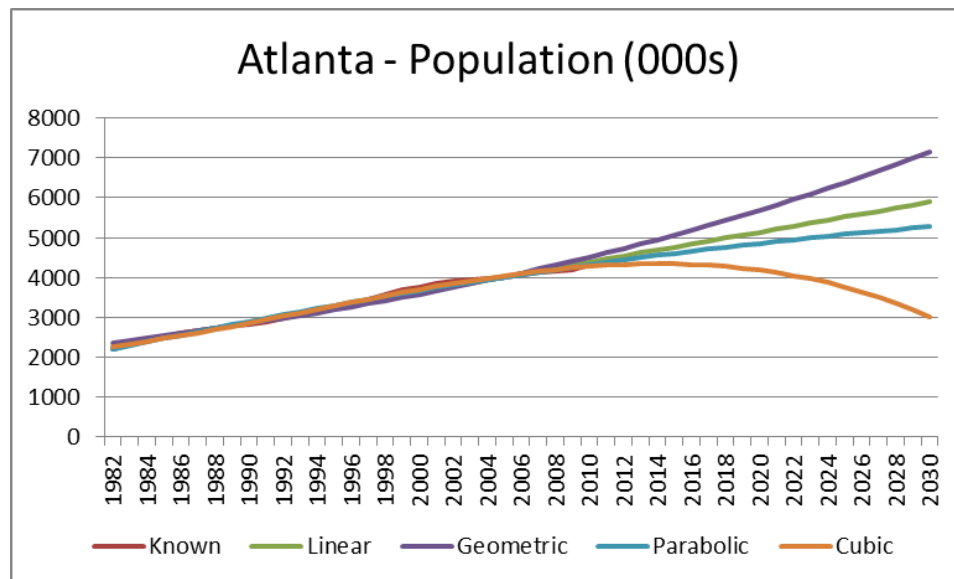
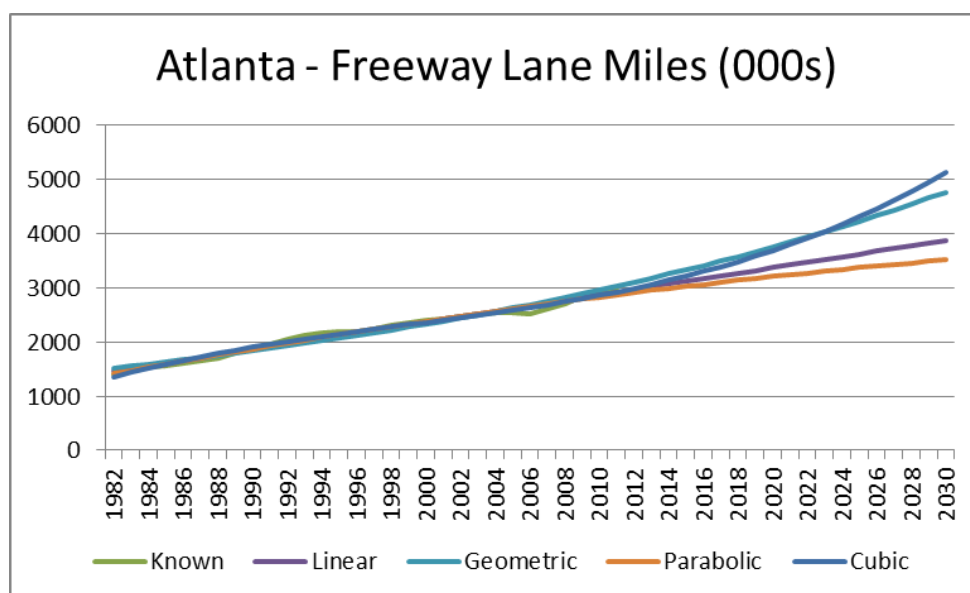


Figure 14



²⁹ Another reason may be that the amount of freeway lanes being built (whether because of costs or space) is not enough to truly fix congestion.

Figure 15

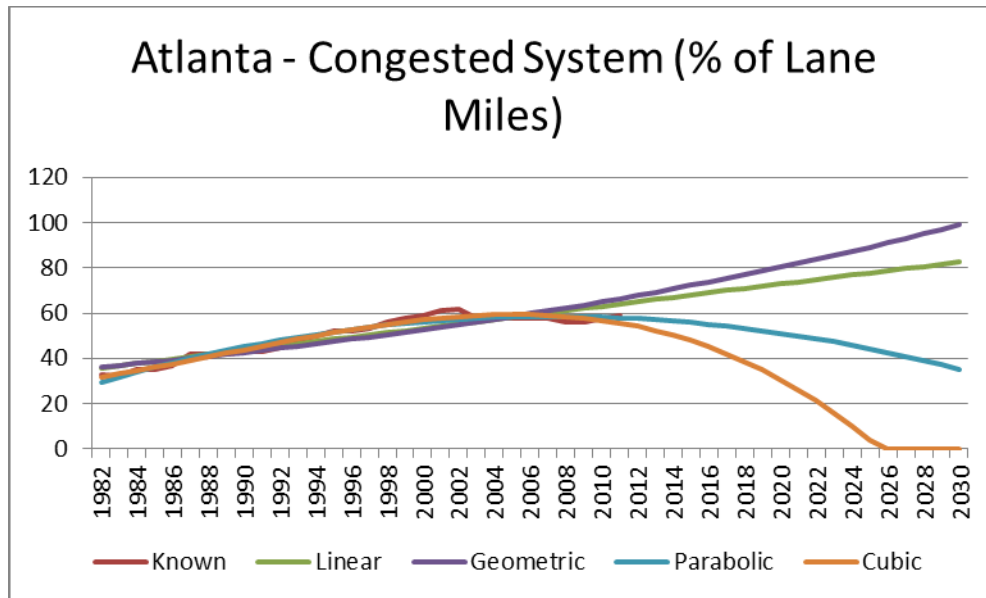


Figure 16

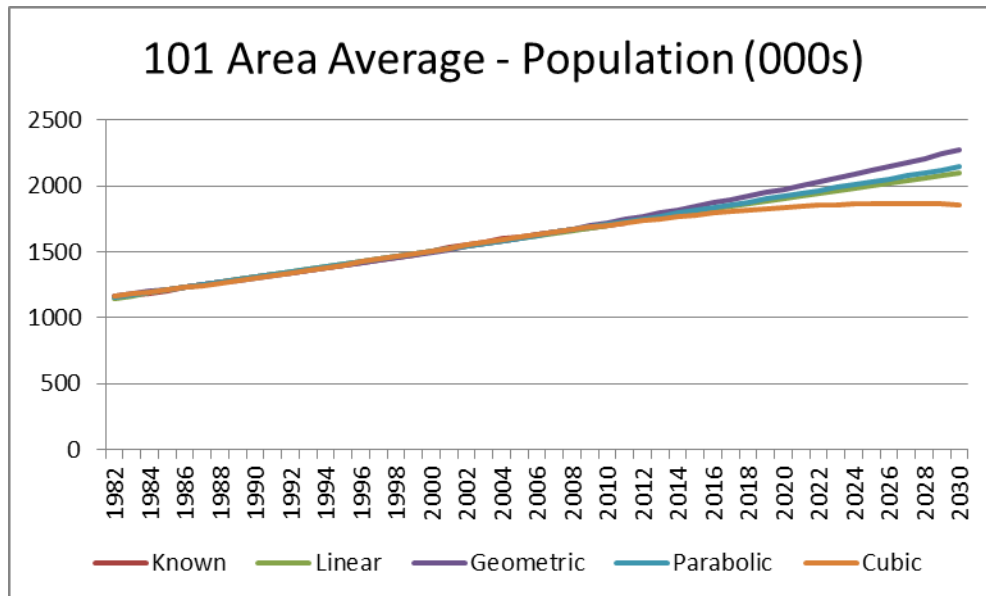


Figure 17

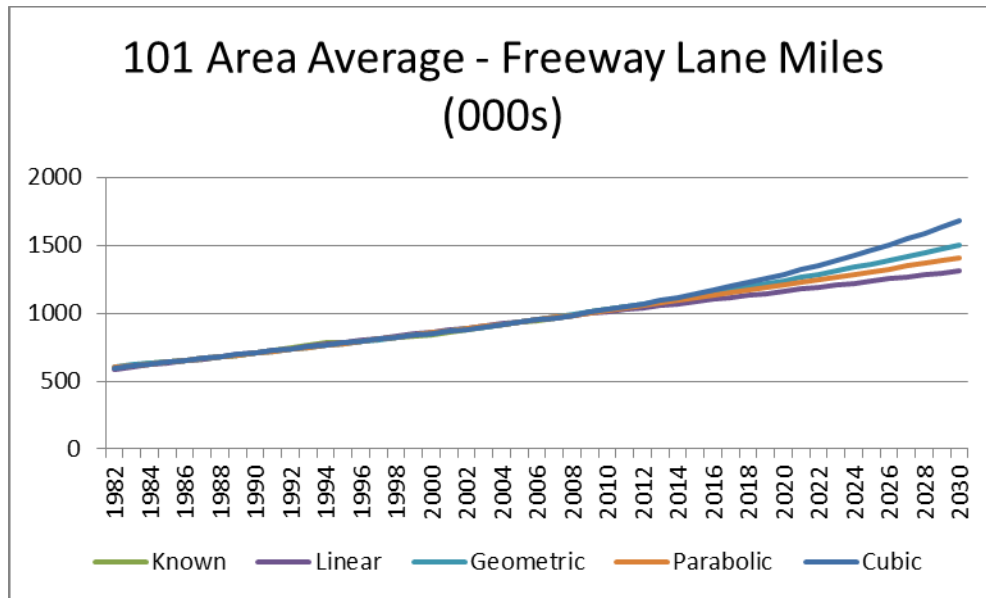
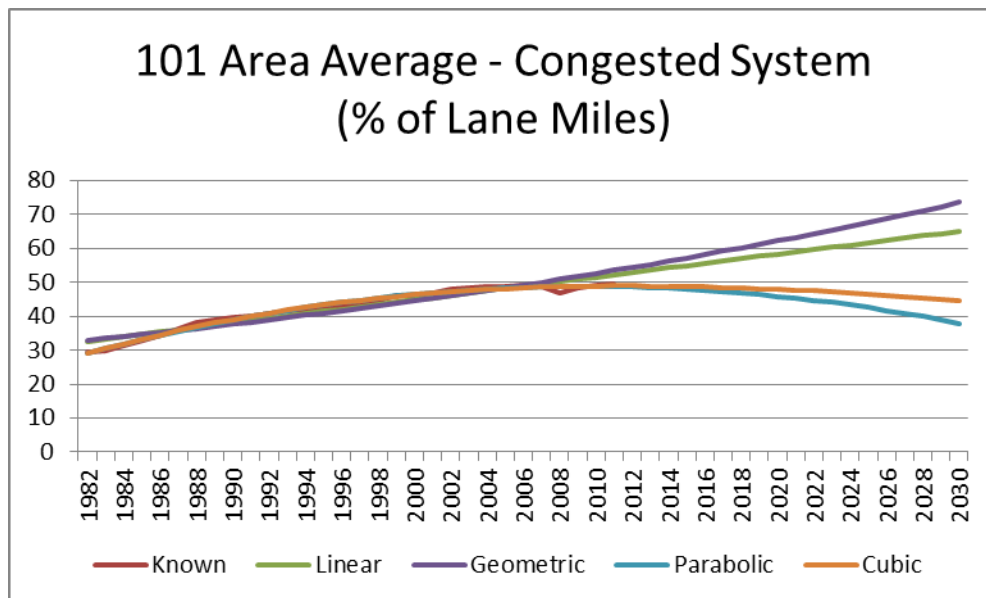


Figure 18



For all of the attention given to congestion on freeways in cities, it is also important to note that urban highways account for only one percent of lane miles (Smith 2012). Another consideration for planners and policymakers is that on average, 30 percent of traffic in central business districts is generated by vehicles seeking to find a parking space close to their

occupants' final destination (Shoup 2007). Thus, planners and policymakers should also look for solutions for congestion on city streets.

(b) *Congestion costs with autonomous vehicles*

Understanding the market failure associated with congestion can help planners and policymakers analyze how autonomous vehicles can impact congestion. First, autonomous vehicles can increase the capacity of the road and drive down travel costs. As discussed in the literature review, autonomous vehicles in a car-sharing model can potentially replace around twelve human driven vehicles, significantly reducing the number of vehicles on the roadway. Further, autonomous technologies can decrease the space between vehicles and thus increase freeway capacity. For example, KPMG estimates that platooning of vehicles could increase highway lane capacity by up to 500 percent (KPMG & CAR 2012).

Second, autonomous vehicles will be more capable of having perfect information than a human driver. This may help reduce some of the social costs not accounted for by individual drivers. During congested periods, an autonomous vehicle could be alerted to take a different route (Newcomb 2014). Further, because autonomous vehicles can potentially reduce the opportunity cost of travel time by allowing a driver to engage in other productive or enjoyable activities while driving, autonomous vehicles could have a major impact in reducing the overall cost of congestion, even if traffic congestion itself is not significantly ameliorated (Anderson et al. 2014).

Finally, autonomous vehicles may reduce the need for increasing the current amount infrastructure. Autonomous transportation may bring an end to battles over the need for more public transportation, as autonomous vehicles might provide a more flexible and less costly

alternative (KPMG & CAR 2012). Further, the need for parking infrastructure may be reduced because autonomous vehicles in a car-sharing model would be in more constant use and people would demand less parking (KPMG & CAR 2012). As discussed in the literature review, a 10 percent reduction in need for infrastructure investment would result in savings of \$7.5 billion per year, or \$75 billion per decade compared to current infrastructure expenditures (KPMG & CAR 2012).

(c) What does this mean to planners and policymakers?

An autonomous vehicle's ability to reduce congestion provides planners and policymakers with the ability to reduce infrastructure expenditures because autonomous vehicles can increase roadway capacity and potentially decrease the number of vehicles on the roadways. Autonomous vehicles would allow planners and policymakers the opportunity to potentially save billions of dollars that would typically go to building extra roadway capacity or building new transportation infrastructure such as rail or bus-rapid-transit. These savings could be used for roadway maintenance or deconstruction of excess highway capacity. Because autonomous vehicles will have close to perfect information, they can better route themselves to avoid over congesting a roadway if a freeway through a city was demolished (a concern among those against highway removal). Planners and policymakers could also use these savings to fund fleets of autonomous vehicles as a new form of public transit. Essentially, planners and policymakers would need to weigh the opportunity costs associated with the decrease in expenditures on infrastructure that could result from autonomous vehicles.

Secondly, autonomous vehicles provide planners and policymakers with the ability to accurately price automobile usage. Because of the technologies that will be available in autonomous vehicles, planners and policymakers may be able to implement pricing schemes that

more accurately reflect the cost of congestion and the potential increase in VMT associated with individually owned and car-shared autonomous vehicles (similar to variable tolling or variable pricing). Under these innovative pricing schemes, a person entering their car, an aTaxi, or shared car could be aware of the costs before driving to a destination. This would allow a rational actor to choose between riding in an autonomous vehicle and/or taking another form of transportation.

Finally, autonomous vehicles provide planners and policymakers with a potential source of revenue and an ability to encourage beneficial development. The American car culture may be declining (Sivak 2013a & Sivak 2014), but much of our urban infrastructure remains centered on the automobile. A forth-coming study by Norman Garrick suggests that minimum parking requirements required in many zoning codes cost cities money (Winter 2014). Garrick's study concludes that some car-centric cities forfeit more than a thousand dollars per parking space per year in potential municipal revenues by using land for parking rather than more lucrative alternatives (Winter 2014). The researchers also found that "minimum parking requirements inhibit development and exacerbate traffic by placing incentive on car use rather than on walking and cycling" (Winter 2014). A world with autonomous vehicles would allow planners and policymakers to reduce parking requirements and recapture the revenue lost by allowing the land to convert to a more valuable use.

A final benefit of eliminating parking in cities is the potential to pass economic savings on to the consumer as well. Currently, the typical automobile is parked for about 95 percent of its lifetime (Shoup 2005). Because driving remains the dominant form of transportation in the United States, the total area devoted to parking spaces in a typical city is about 31 percent (Manville & Shoup 2004). A typical parking space in a city can cost between \$4000 and

\$40000 to build. If a zoning code allowed a maximum number of 1250 parking spaces, then building parking would cost a developer about \$18,750,000 (See Tables 2 & 3).³⁰ For a building that sells for about \$150,000,000, this means that parking accounts for about 12.85% of the building value.³¹

Table 2

Assumptions			
\$/Space of Parking (Construction) - City	\$15,000		
\$/Space of Parking (Construction) - Suburb	\$5,000		
# of Spaces for a Development	Small	Medium	Large
	250	750	1250

Table 3

Savings to Development by not building parking	City	Suburb
Small	\$3,750,000	\$1,250,000
Medium	\$11,250,000	\$3,750,000
Large	\$18,750,000	\$6,250,000

If a developer did not have to build parking spaces, the total cost of development could be reduced significantly. This reduction in development costs could result in more land being converted to valuable uses, more projects being financially viable, and potentially more housing options – some of which may be affordable – to be built in the city near jobs.

(4.3) Cost of Vehicle Ownership – Social Costs

In addition to the congestion and infrastructure costs associated with automobile ownership, automobile ownership also results in social costs related to traffic accidents and traffic fatalities. Autonomous vehicles potentially provide a way to reduce the social and monetary costs associated with traffic accidents and traffic fatalities.

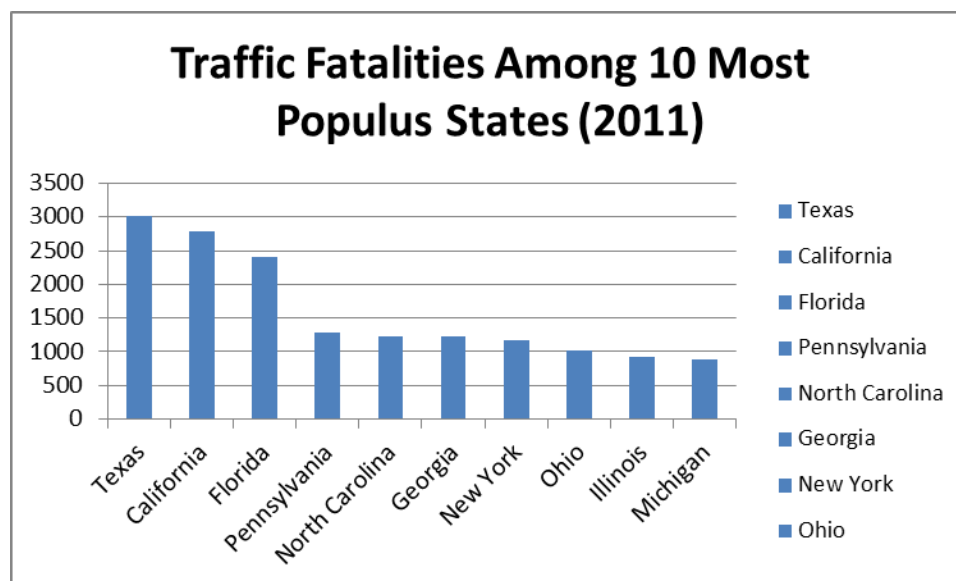
³⁰ This assumes that each parking space costs \$15,000 to build

³¹ This calculation uses recent sales data for Two Alliance Center in Atlanta, GA. The maximum allowable parking for this area would be 1250.

(a) Current data on traffic accidents and fatalities

About 93 percent of traffic accidents can be attributed to human error (Maddox 2012). In 2009, 5.5 million motor vehicle accidents occurred in U.S. These accidents killed 33,808 people and injured more than 2.2 million others – 240,000 of whom had to be hospitalized.³² In 2011, 5.3 million motor vehicle accidents occurred in the U.S. These accidents killed 32,367 people.³³ Almost half of these accidents can be attributed to the 10 most populous states (See Figure 19).

Figure 19³⁴



The estimated cost of automobile accidents in the 99 largest U.S. urban areas was \$299.5 billion (AAA 2011).³⁵ Adjusting those numbers to cover the entire country suggests annual costs of about \$450 billion (AAA 2011). Further, if we project traffic fatalities out to 2030, the numbers suggest that there may be anywhere between 7,000 and 70,000 traffic fatalities in the year 2030

³² National Highway Traffic Safety Administration. Available at <http://www-nrd.nhtsa.dot.gov/CMSWeb/index.aspx>.

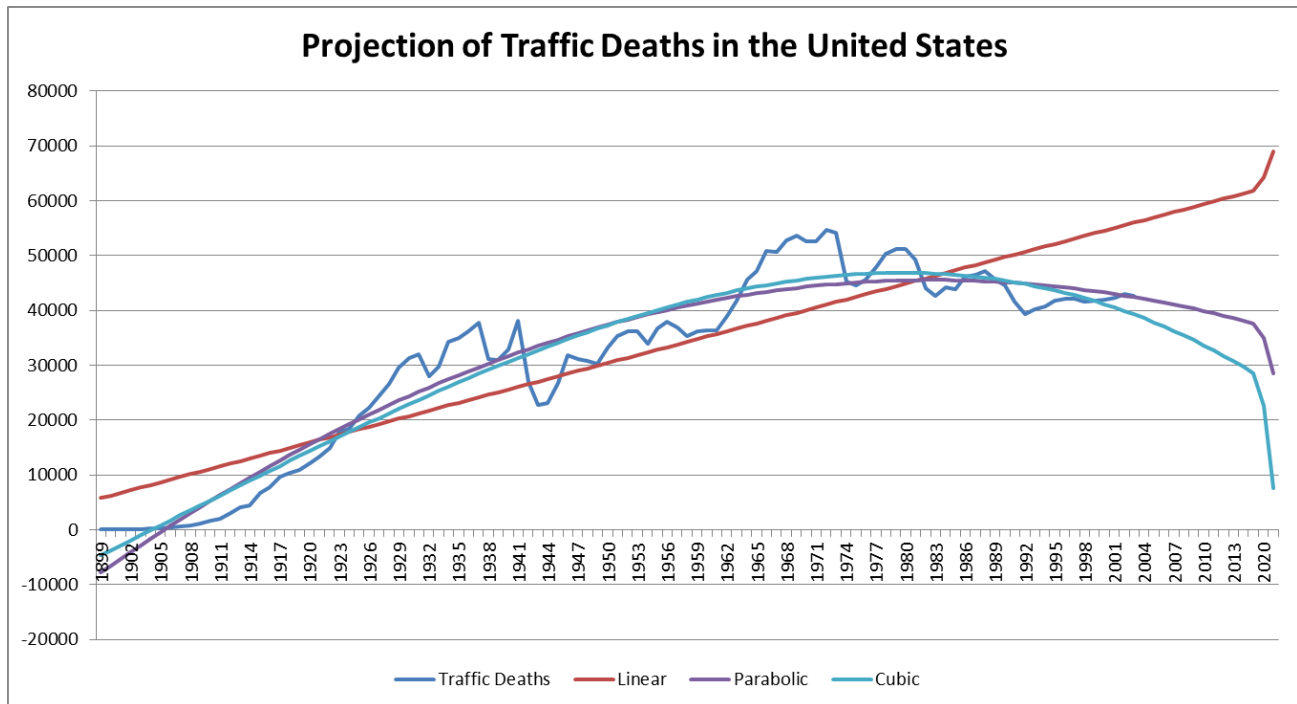
³³ National Highway Traffic Safety Administration. Available at <http://www-nrd.nhtsa.dot.gov/CMSWeb/index.aspx>.

³⁴ Data from 2011 NHTSA traffic fatalities and fatality rates

³⁵ This report added up all the costs related to automobile accidents – including medical costs, property damage, loss of productivity, legal costs, travel delays, pain and suffering, and lost quality of life.

(See Figure 20). Historical data suggests that traffic fatalities have steadily decreased, likely due to technological innovations.

Figure 20³⁶



(b) *Social costs with autonomous vehicles*

Safety experts believe that having computers in charge of things that they are good at will cut down on dangerous driver mistakes (Newman 2013). According to the lead developer of the Google Car, driverless car technology has the very real potential to save millions from death and injury and eliminate hundreds of billions of dollars of costs (Mui 2013). Google anticipates that autonomous vehicles have the potential to reduce traffic accidents by 90% (Mui 2013). Based off of current data, Google's claims mean that a United States with autonomous vehicles would have resulted in more than 4.5 million fewer accidents in 2009 and 2011. Further, there would

³⁶ Data from: <http://www-fars.nhtsa.dot.gov/Main/index.aspx>

have been close to 30,000 fewer fatalities in those years as well. Finally, autonomous vehicles could potentially result in over \$400 billion less in accident-related expenses.

(c) What does this mean to planners and policymakers?

For policymakers and planners, autonomous vehicles promise society a potentially greater quality of life. By encouraging autonomous vehicles, or at least the technology, planners and policymakers can help reduce the number of automobile accidents, automobile related deaths, and costs associated with automobile accidents. A reduction in social costs associated with automobile use means that automobiles will be a means of safer and less costly transportation from a human capital perspective. Further, once autonomous vehicles reach the Level 4 stage of autonomy, they may allow more members of society – namely the elderly and the young – to safely commute independently.

(4.4) Cost of Automobile Usage – Emissions

One final cost associated with automobile ownership is petroleum and vehicle emissions. Autonomous vehicles may be able to help with these issues by reducing excess emissions attributable to congestion, reducing the number of cars on the road, and allowing alternative fuel sources to be more easily used.

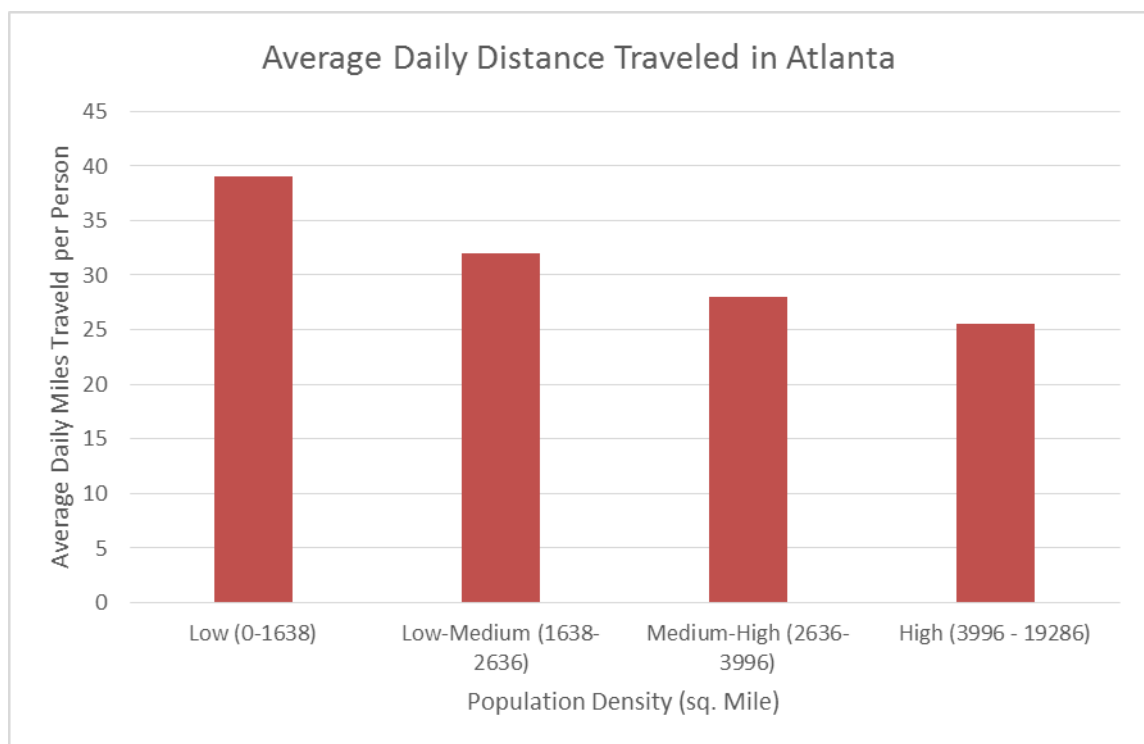
(a) Current data on emissions

Currently, passenger vehicles are a major contributor to emissions and conventional air pollution such as smog and ground-level ozone (Anderson et al. 2014). Recent data from the EPA suggest that the use of light-duty passenger vehicles in the United State contributes to around 17 percent of national greenhouse gas (GHG) emissions (EPA 2014). Further,

approximately 60 percent of petroleum usage is attributable to the passenger vehicles (Anderson et al. 2014 & Davis et al. 2012).

The amount of automobile emissions and petroleum use can be attributed, in part, to vehicle miles traveled (VMT). As discussed in the literature review, increased VMT can partially be attributed to sprawl. This less dense form of development can cause individuals to have to drive more and farther to reach activities (see e.g. Ewing & Hamidi 2014). Analyzing data from the year 2000 Strategies for Metropolitan Atlanta's Regional Transportation (ARC) and Air Quality study further shows that, on average, daily miles traveled decreases as population density increases in Atlanta (See Figure 21).³⁷

Figure 21



³⁷ This data was combined with ARC land use data and U.S. Census Bureau data. Population density was divided into quartiles and the average VMT was taken for individuals falling into the density quartiles.

By using data from the Texas A&M Urban Mobility Report, we can project some of the negative effects of VMT and congestion associated with commuting such as increased CO2 and excess fuel consumed out to 2030 for the Atlanta region and the 101 area average (See Figures 22-25). Current data suggests that these values may continue to get worse under a “business-as-usual” approach.

Figure 22

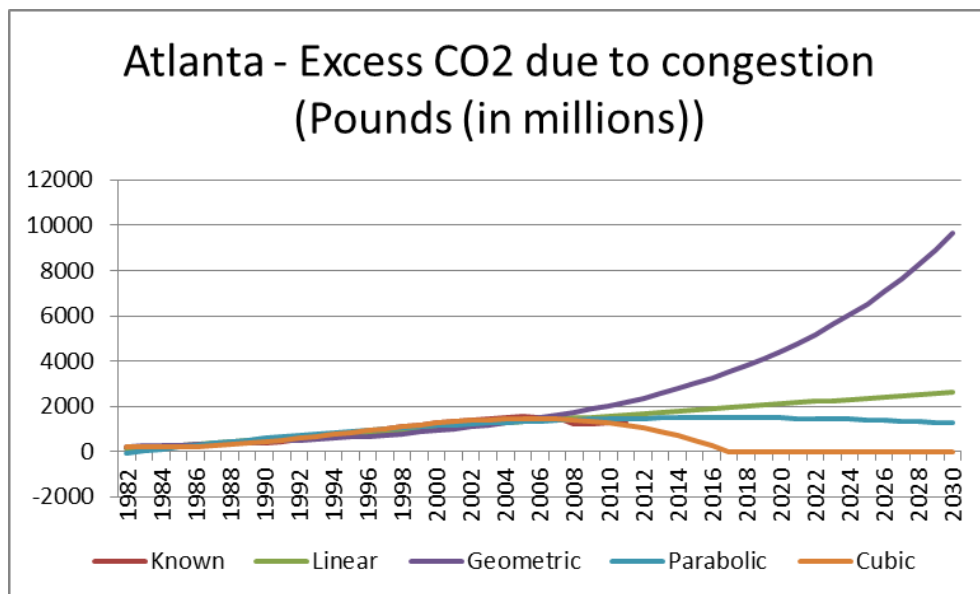


Figure 23

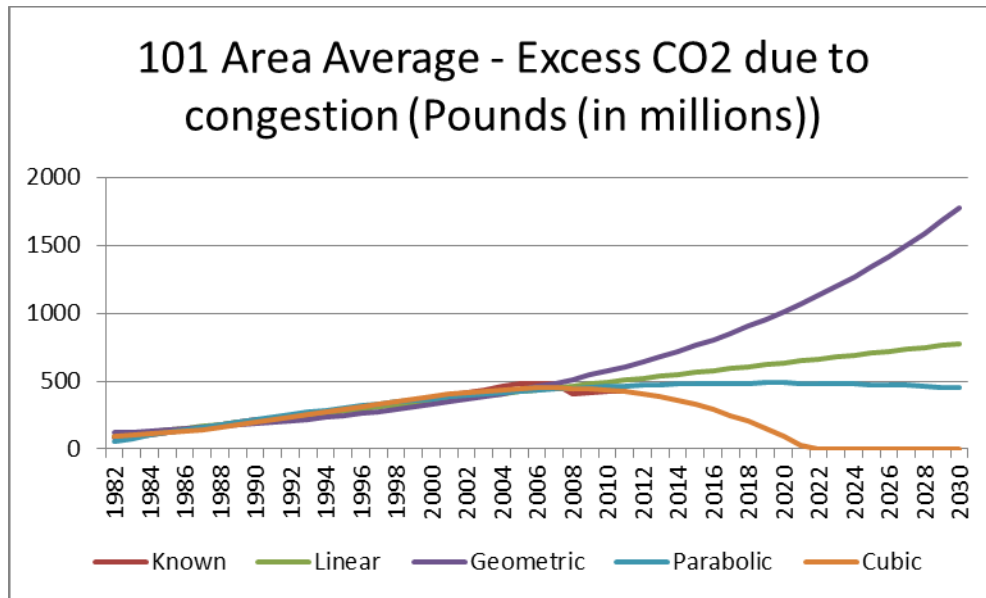


Figure 24

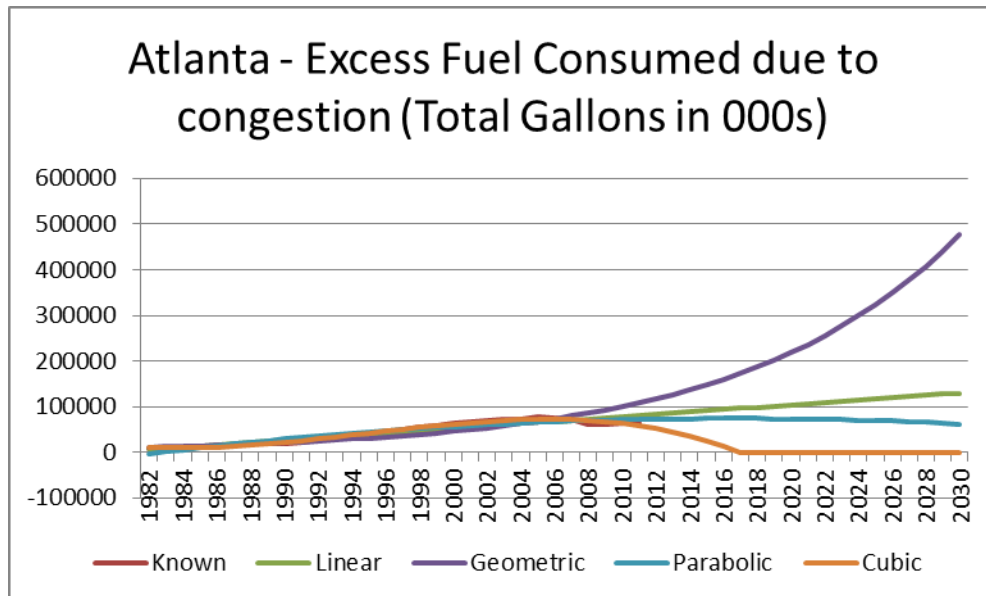
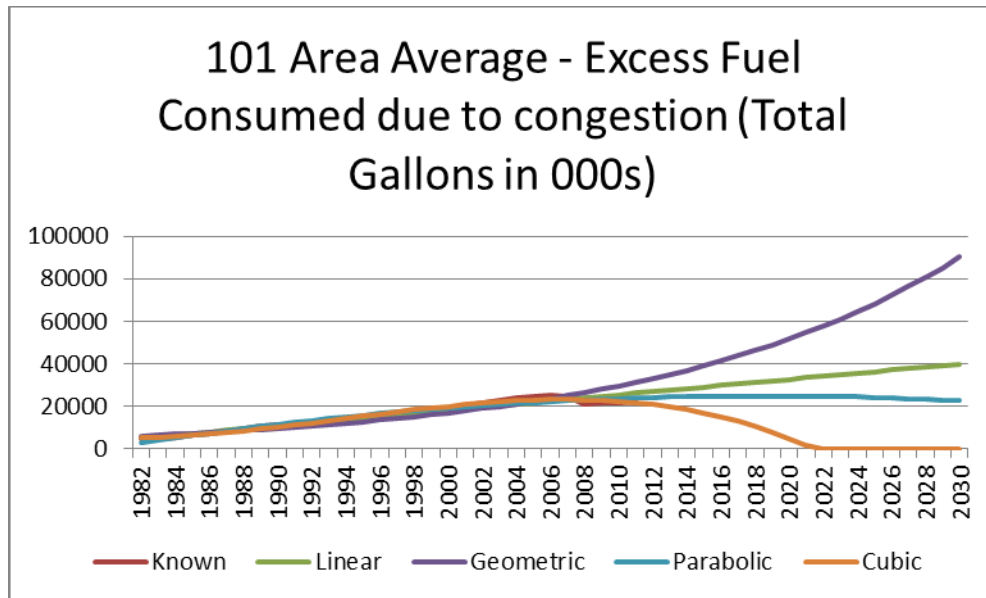


Figure 25



(b) *Emissions with autonomous vehicles*

The transition to autonomous vehicles has the potential to substantially affect GHG emissions and air pollution. Further, autonomous vehicles, due to their improved safety and driving capabilities, may substantially reduce automobile gasoline usage. Research shows that autonomous technologies can create a smoother, more free-flowing traffic flow that will result in better gas mileage and lower vehicle emissions, but whether autonomous vehicles improve or worsen energy use and environmental outcomes will likely depend on the fuel efficiency of autonomous vehicles, the number of autonomous vehicles on the road, and the change in VMT resulting from the use of autonomous vehicles.

Research shows that autonomous vehicles will have varying effects on the cost of mobility, VMT, and car ownership (Anderson et al. 2014; Burns et al. 2013; & Spieser et al. 2014). At this point, it may still be too early and too speculative to determine the exact effect autonomous vehicles will have on these factors, but research shows that reduced travel costs can

lead to increased VMT (or rebound effect). Further, NHTSA data shows that with a 10-percent rebound effect assumption, if per-mile vehicle costs fall by 20 percent, VMT demand will rise by 2 percent (Anderson et al., 2014). Further, while traditional car-sharing studies estimate that North American car-sharing members reduce their driving distances by 27% (Shaheen & Cohen 2013), the Fagnant and Kockelman model discussed in the literature review showed that with SAVs, vehicle miles traveled actually increased (likely due to the decreased cost of vehicle travel). This suggests that even though emissions per vehicle mile traveled may decrease, total emissions may actually increase due to increased VMT (Smith 2012). Much of this increase will likely depend on the number of automobiles SAVs replace.

Currently, if you took the number of commuters in Atlanta – 2,135,000 – and assumed that they each drove alone and that they drove on average 31 miles per day – the average VMT in Atlanta from 2001 to 2011 – then those automobiles would produce 7,083,274.3 metric tons of CO₂ per year (assuming 30.2 miles per gallon).³⁸ If all of those cars were electric and got 3.03 miles per kWh – the fuel efficiency of a Tesla – then the same number of automobiles would be responsible for 4,653,349.5 metric tons of CO₂ per year.³⁹ Thus, using all electric vehicles results in a 34.3 percent reduction in the amount of CO₂ emissions over gasoline powered vehicles (See Tables 4 & 5).

Having set the baseline for current emissions, this baseline can be compared to a world with autonomous vehicles. Current research suggests that one autonomous vehicle can replace around 12 human driven vehicles (Fagnant and Kockelman 2014). Further, if we take the

³⁸ Number of commuters is from the Texas A&M Urban Mobility Report; 31 miles is the average VMT for someone in Atlanta over the years 2001 to 2011. This was found using data from the Department of Transportation. Available at: <https://www.fhwa.dot.gov/policyinformation/statistics.cfm>; 30.2 is the CAFÉ standard for passenger vehicles as of 2011; CO₂ emissions for gasoline vehicles was found using the 2010 number of 8855 grams CO₂/unit of fuel.

³⁹ CO₂ emissions for electric vehicles was found using the 2010 number of 603.17 g CO₂/kwh

NHTSA rebound rate and the reduction in driving costs found in the Spieser research (50 percent), each driver should increase their VMT by five percent. This means that each vehicle is driving 12 people a total of 391 miles per day. So, 177,917 gasoline powered autonomous automobiles driving 391 miles per day now equates to 7,445,054.44 metric tons of CO2 per year (a 5.1 percent increase in CO2 emissions). For electric powered vehicles, 177,917 autonomous vehicles are now responsible for 5,041,128.611 metric tons of CO2 per year (an 8.3 percent increase in CO2 emissions). But, if VMT saw reduction like those seen in car share models, the emissions for gasoline powered autonomous vehicles would be 5,160,127.246 metric tons CO2 per year (a 27.2 percent reduction in emissions). Emissions from electric vehicles would be 3,490,012.115 metric tons CO2 (a 25 percent reduction in emissions) (See Tables 4 &5).

Table 4

Knowns	
Vehicles	2,135,000
SAV Vehicles	177,917
Miles/unit fuel (elect)	3.03
Miles/unit fuel (gas)	30.20
National Magic # for Gas (g CO2/unit of fuel)	8,855
National Magic Number for Electric power (g co2/kwh)	603.17

Table 5

	Miles Driven Per day	Metric Tons CO2/year (Electric)	Metric Tons CO2 /year (gasoline)
Current	31	4,653,349.5	7,083,274.3
With SAVs and increased VMT	391	5041128.611	7445054.44
With SAVs and Car-share VMT	271	3490012.115	5160127.246

Unfortunately, knowing the emissions for an autonomous vehicle world is slightly more complicated than the calculation above. First, it is tough to predict whether households will individually own an autonomous vehicle, or if they will be part of an autonomous vehicle car

share. Second, increases in total VMT may have a neutral effect on energy and environmental impacts if gasoline powered or electric automobiles see increases in fuel efficiencies due to autonomous technology and/or if GHG intensities of fuels are reduced (i.e. solar charging stations becoming viable or biofuels with less intense emissions). Finally, the emergence of Level 4 AV taxis and car-sharing services may induce additional VMT demand from new sources. These include the elderly, the young, those without driver's licenses, and those who now value the time or multi-task opportunities afforded by driverless taxis over other modes of transportation. Regardless of the uncertainty, autonomous vehicles pose a potential threat to emissions reduction.

(c) What does this mean to planners and policymakers?

Unlike the other benefits associated with autonomous vehicles, emissions reduction is the most uncertain. Given the amount of GHG emissions associated with transportation and some of the dire warnings given by the recent IPCC report on climate change, figuring out solutions for the potential increase in GHG emissions associated with autonomous vehicles will be vitally important. Potential solutions could be encouraging electric vehicles and electric vehicle charging infrastructure – particularly solar or wind powered. This may help reduce emissions even if VMT increases.

Other solutions could involve encouraging more reduction in vehicle ownership through incentivizing car-sharing/carpooling (see i.e. Fellow & Pitfield 2000). Further, as discussed in the literature review, vehicle usage can be influenced by greater density and better access to activities. Thankfully, autonomous vehicles may help encourage these through their need for less parking and infrastructure in cities. Thus, it will be important for planners and policymakers to facilitate this further.

One final solution for reducing emission may be to make the use of autonomous vehicles in certain areas of the city less appealing by making them cost more or by regulating the speed or time of travel in these areas (see i.e., Chatman 2008).

(5) A Weighing of Costs and Benefits

As discussed throughout section 3 of this paper, autonomous vehicles have many potential benefits over our current automobile state. However, there are very real costs such as the potential to increase VMT and increase the cost of purchasing and owning a vehicle. Further, despite the potential economic potential associated with autonomous vehicles, autonomous vehicle represent a threat to jobs such as taxi drivers, bus drivers, long-haul truckers, and other transport service jobs. Finally, there is also the hurdle of getting people to a point where they are ready to cede control to computers. For this technology to progress, it will be necessary to weigh the potential costs and benefits to make a determination as to how to proceed forward with this technology.

A table of the costs and benefits discussed in this paper is provided below (See Table 6). Outside of these basic costs and benefits, planners and policymakers will want to keep up with forthcoming research to stay apprised of the true impact of these costs and benefit. Further, new research may show that are additional costs and benefits that we are not currently aware of. Understanding this technology will help planners and policymakers maximize the potential benefits while minimizing the costs.

Table 6

Self-Driving Vehicle Benefits & Costs	
Benefits	Costs
<ul style="list-style-type: none"> • Fewer Traffic Accidents • Fewer vehicle related fatalities • Reduced Gridlock • Increased Highway capacity • Improved Transit Time • Reduced Fuel consumption • Reduction in the number of vehicles • Lower Greenhouse Gas Emissions due to less idling and better fuel efficiency • Potential new infrastructure leading to Economic Development Opportunities and job creation • Increased Quality of life for those unable to drive currently • Greater mobility and accessibility • Reduced stress associated with travel and traffic • Increased worker productivity • New economic opportunities for vehicle owners (e.g. potential for car sharing/ride sharing) 	<ul style="list-style-type: none"> • High costs to purchase • Potential increase in VMT • Potential increases in GHG emissions due to increased VMT • Data privacy and security issues • May replace many driver dependent jobs • Potential for more gridlock • May encourage sprawl (Economic and Social costs associated with this) • Potential infrastructure costs if autonomous vehicles require special infrastructure • Overcoming resistance/hesitance of humans ceding control to computers

(6) Current Barriers to be Aware of

Currently, one major difficulty with planning for autonomous vehicles is the fact that decision makers are trying to adopt a legal and policy framework for an evolving technology. Further, as of today, no automotive manufacturers have a Level 4 autonomous vehicle and no significant testing in the public sphere is being done with these vehicles. Because of this, we

cannot be sure of the true impact this technology will have on our transportation system. However, jurisdictions like Nevada, Florida, California, and Washington D.C. have passed legislation that will begin to set the framework for this technology. As this technology continues to evolve, the legislative framework will need to be able to address the emerging legal issues and emerging costs associated with implementation. The difficult task for decision makers involves drafting a flexible policy framework that can evolve with the technology and forecast where the technology is going. Outside of Nevada, California, Florida, and Washington D.C., a framework for autonomous vehicles does not exist. However, as more research is done and as more is understood about the technology, this will change.

(7) Conclusion

This paper sought to answer the question of “whether autonomous vehicles provide a potentially better source of transportation than current transportation options such as the automobile? And, if so, what some of the impacts, costs, and benefits autonomous vehicles will have on society and the built environment?” The data provided throughout this paper tends to indicate that autonomous vehicles will have many benefits over our current automobile use. Further, in some instances, such as with shared autonomous vehicles, autonomous vehicles may provide a cheaper alternative with better access and wait times than public transportation. But, autonomous vehicles do not come without their costs (i.e., environmental impacts and potential job loss). Without understanding these types of costs and benefits, planners and policymakers will not be able to maximize the potential of autonomous vehicles.

Because many policies and land use changes can take years to be fully realized, planners and policymakers should be thinking about the impact that this technology will have on society and the urban environment. Now is the time to start planning for this technology, at least

broadly, so that we do not make the same mistakes we made with the automobile. Even if the policy and legal issues currently facing autonomous vehicles take time to solve, planners and policymakers would be wise to begin thinking about the impacts of autonomous vehicles discussed in this paper. By thinking about the benefits and costs now, planners and policymakers can attempt to establish a framework that will minimize the costs while maximizing the benefits. For example, planners can start looking at reduced parking, increased density, less roads, and more alternative means of moving about our built environment. With this technology, planners have the opportunity to reclaim the built environment for the pedestrian. Further, planners can begin thinking about the way this technology will change transportation planning and funding. Policymakers, on the other hand, can look at the social equity and economic benefits of the technology.

(7.1) Next Steps

As stated previously, the United States will likely remain automobile dependent for the foreseeable future, but autonomous vehicles allow planners and policymakers to minimize the negative aspects of automobiles and potentially shift from accommodating the automobile to embracing the automobile as a part of our society but not the focus of our built environment. No longer do we have to find ways to change peoples' views on the automobile; instead, we can let the technology help improve upon the negatives of the automobile. Then, we can embrace the automobile without having to continue to build our urban environment around the automobile.

Shifting from mainly planning for and making places for the automobile, to creating an urban environment focused on the human scale, should delight planners. For most of us, helping improve cities and improve the quality of life is part of the reason we chose this profession. If technology presents the opportunity to help us accomplish these goals, we should at least

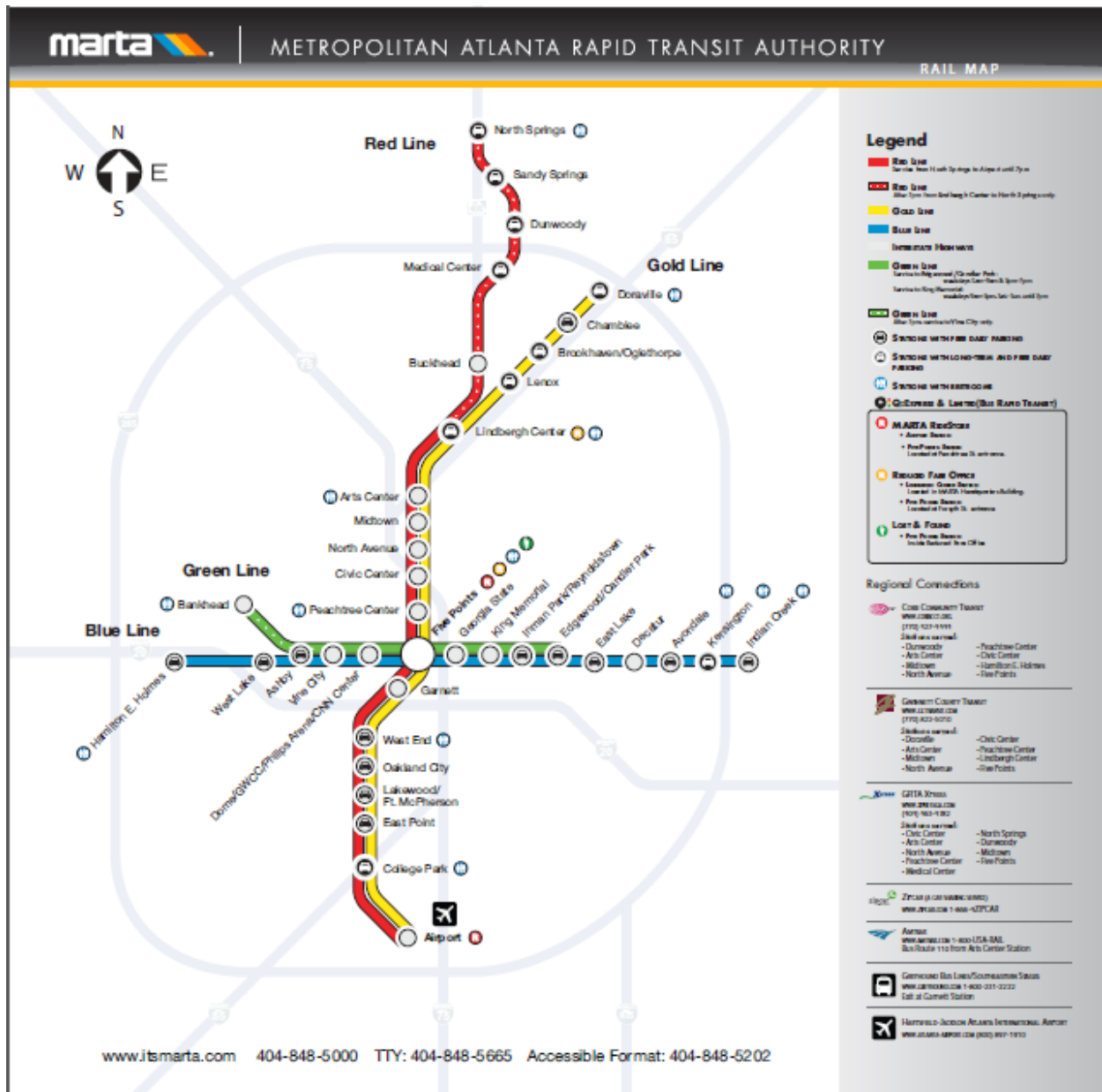
consider it. In order to best embrace the benefits of this technology, we should be aware of what the technology is and the challenges and benefits that come along with it. Going forward, there is still more that needs to be done to inform us about this technology. But, as more people begin to model the impacts of autonomous vehicles, and as recently announced tests of Level 3 vehicles in the public sphere produce data, we will begin to have better data and understandings of the true benefits autonomous vehicles can provide to our cities. This data can be used to update some of the projections and numbers used in this report, and can be incorporated in to models such as those in the Spieser et al., Burns et al., and Fagnant & Kockelman studies. Gathering more data as it becomes available will continue to help planners and policymakers understand the impacts, costs, and benefits of this technology.

Appendix A: Table of Legislation

State	Bill Number	Date Introduced
Arizona	HB 2679	1/30/2012
Arizona	HB 2167	1/23/2013
California	AB 2258	2/21/2014
Colorado	SB 13-016	1/9/2013
Florida	SB 1768	1/6/2012
Georgia	SB 369	2/7/2014
Georgia	HR 1265	2/6/2014
Hawaii	HB 2420	1/23/2014
Hawaii	HB 1461	1/24/2013
Hawaii	HB 2238	1/23/2012
Hawaii	HR 163	3/14/2012
Louisiana	HB 937	2/28/2014
Louisiana	HB 938	2/28/2014
Maryland	SB 773	1/31/2014
Maryland	HB 538	1/29/2014
Massachusetts	HB 3369	1/22/2013

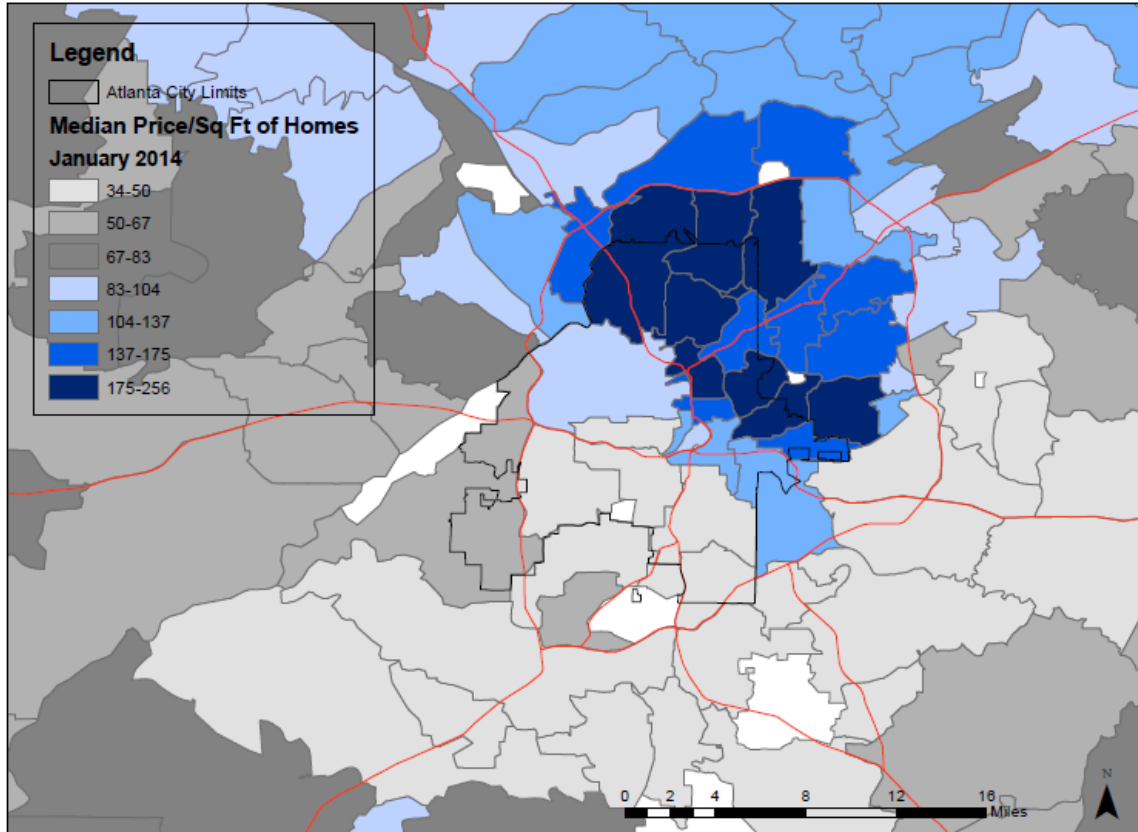
State	Bill Number	Date Introduced
Michigan	SB 169	2/7/2013
Minnesota	HF 1580	3/14/2013
Nevada	R 084-11	3/1/2012
New Hampshire	HB 444	1/3/2013
New Jersey	S 2898	6/24/2013
New Jersey	S 734	1/14/2014
New Jersey	A 1326	1/14/2014
New Jersey	A 2757	5/10/2012
New Jersey	A 3020	6/7/2012
New York	S 4912	5/1/2013
Oklahoma	HB 3007	1/19/2012
Oregon	HB 2428	1/14/2013
South Carolina	HB 4621	2/6/2014
South Carolina	HB 4015	4/24/2013
South Dakota	SB 139	1/31/2014
Texas	HB 2932	3/7/2013
Washington	HB 1439	1/28/2013
Washington	HB 1649	2/4/2013
Wisconsin	SB 80	3/13/2013

Appendix B: Transportation Map

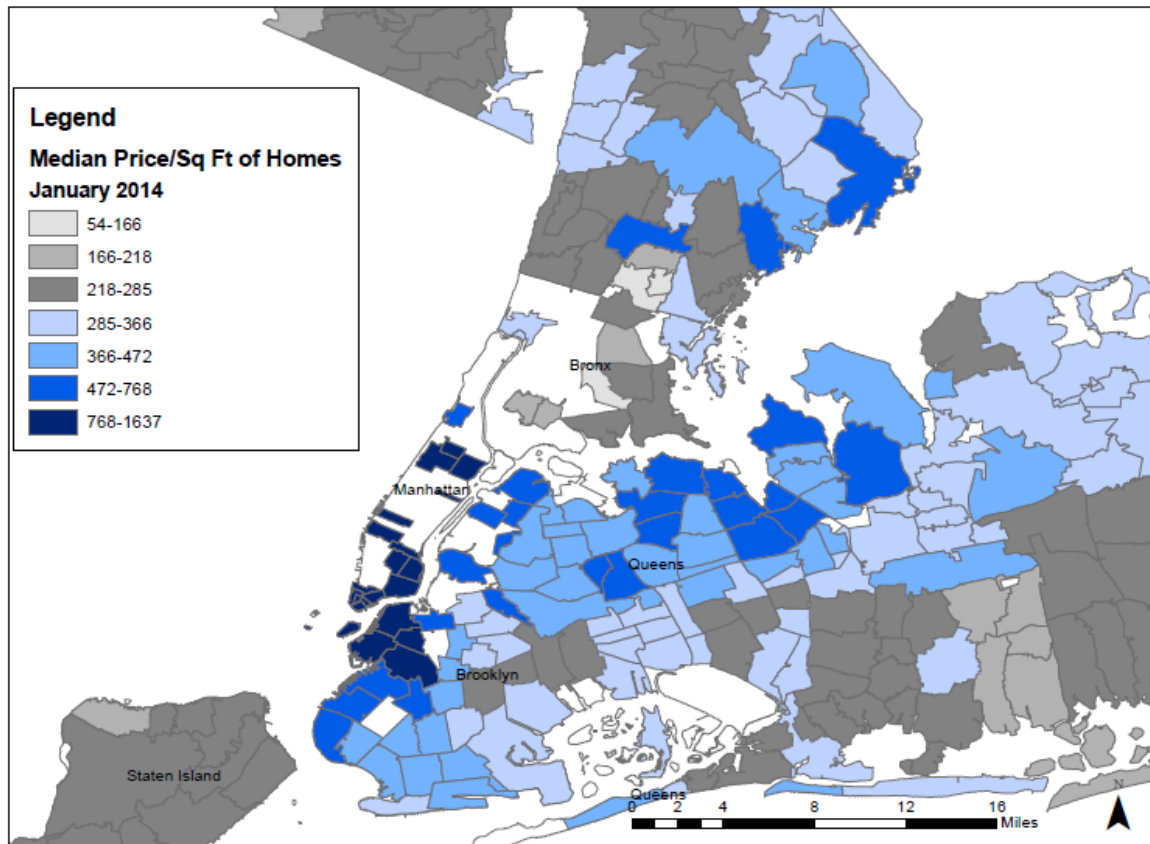


Appendix C: Bid Rent Maps

Atlanta Bid Rent Curve



New York City Bid Rent Curve



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